

FINAL

Remedial Process Optimization Report for Site 5/15 Contaminant Plume South Base Operable Unit No. 2



**Edwards Air Force Base
California**

Prepared For

**Consultant Operations Division
Brooks Air Force Base
San Antonio, Texas**

and

**U.S. Air Force Flight Test Center
Environmental Management Office
Edwards Air Force Base, California**

February 2000

FINAL
REMEDIAL PROCESS OPTIMIZATION REPORT
FOR
SITE 5/15 CONTAMINANT PLUME
SOUTH BASE OPERABLE UNIT No. 2
EDWARDS AIR FORCE BASE, CALIFORNIA

Prepared for:

CONSULTANT OPERATIONS DIVISION
BROOKS AIR FORCE BASE, TEXAS

and

US AIR FORCE FLIGHT TEST CENTER
ENVIRONMENTAL MANAGEMENT OFFICE
EDWARDS AIR FORCE BASE, CALIFORNIA 93524-1130

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Contaminant Plume

LIST OF ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence/Technology Transfer Division
AMC	Air Mobility Command
ARARs	Applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
bgs	Below ground surface
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CAHs	Chlorinated aliphatic hydrocarbons
CDHS	California Department of Health Services
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COPC	Chemicals of Potential Concern
CRWQCB	California Regional Water Quality Control Board
CSM	Conceptual site model
CTF	Combined Test Force
DES	Dual extraction system
DEWs	Dual extraction wells
DNAPLs	Dense nonaqueous-phase liquids
DO	Dissolve oxygen
DoD	Department of Defense
DTSC	Department of Toxic Substances Control
Earth Tech	Earth Technology Corporation
EDB	Ethylene dibromide
EE/CA	Engineering evaluation/cost analysis
°F	Degrees Fahrenheit
FFA	Federal Facilities Agreement
ft/day	Feet per day
ft/ft	Foot per foot
ft/yr	Feet per year
GAC	Granular activated carbon
gpm	Gallons per minute
HASP	Health and Safety Plan
ICP	Inductively coupled plasma
IMF	Integrated Maintenance Facility
IRAs	Interim removal actions
IRP	Installation Restoration Program
ITIR	Informal Technical Information Report
LNAPL	Light nonaqueous-phase liquid
LPAS	Low-Profile Air Stripper
LTM	Long-term monitoring
LWQB	Lahontan Water Quality Board

M	Million
MCL	Maximum contaminant level
µg/L	Micrograms per liter
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
MNA	Monitored natural attenuation
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
O&M	Operations and maintenance
OM&M	Operation, maintenance, and monitoring
OPS	Operating properly and successfully
OU 2	Operable Unit 2
Parsons ES	Parsons Engineering Science, Inc.
POL	Petroleum, oils, and lubricants
PRGs	Preliminary remediation goals
PRL	Potential release location
QA	Quality assurance
QAPP	Quality Assurance Program Plan
RAOs	Remedial action objectives
RBCA	Risk-based corrective action
RI/FS	Remedial Investigation/Feasibility Study
RNA	Remediation by natural attenuation
ROD	Record of Decision
RPMs	Remedial Project Managers
RPO	Remedial process optimization
SACM	Superfund accelerated cleanup model
scfm	Standard cubic feet per minute
SOW	Statement of work
SVE	Soil vapor extraction
TCE	Trichloroethene
TDLs	Total designated levels
TDS	Total dissolved solids
TEPH	Total extractable petroleum hydrocarbons
TI	Technical impracticability
1,1,1-TCA	1,1,1-trichloroethane
TSF	Technical Support Facility
TSSR	Treatability Study Status Report
TSWP	Treatability Study Work Plan
TVPH	Total volatile petroleum hydrocarbons
US	United States
USAF	United States Air Force
USEPA	US Environmental Protection Agency
UST	Underground storage tank
VEWs	Vapor extraction wells
VOC	Volatile organic compound

EXECUTIVE SUMMARY

Parsons Engineering Science, Inc. (Parsons ES) prepared a draft remedial process optimization (RPO) handbook for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT). The handbook will be used by AFCEE to review the performance of existing remediation systems, implement performance enhancements on existing systems, perform 5-year record-of-decision reviews, and prepare documentation for “Operating Properly and Successfully” (OPS) certification for sites at Air Force facilities. Parsons ES is field-testing the approach described in the draft handbook at multiple Air Force sites including the Sites 5 and 15 Contaminant Plume (Site 5/15), and affected downgradient Sites 85 and 14, Operable Unit 2 (OU 2), South Base at Edwards Air Force Base (AFB), California. Lessons learned from the RPO field tests will be incorporated into the final RPO handbook. The Air Force goals for the RPO program are 1) assess the effectiveness of the remedial action; 2) enhance the efficiency of the remedial actions; and 3) when possible, identify annual operating, maintenance, and monitoring (OM&M) cost savings in excess of 20 percent for each system evaluated.

At Edwards AFB, the Air Force is implementing a non-time-critical interim removal action (IRA) to address soil and groundwater contaminated with petroleum hydrocarbons, chlorinated aromatic hydrocarbons, and light nonaqueous-phase liquids (LNAPLs) associated with the Site 5/15 contaminant plume. The plume emanates from Site 5, the location of the former waste petroleum, oils, and lubricants storage area, and migrates below the southwest corner of Site 15, the location of the former Flight Test Center and the Maintenance and Support facilities. Site investigations conducted under the Air Force Installation Restoration Program (IRP) have identified solvent- and petroleum-hydrocarbon-contaminated soil underlying Site 5. The groundwater portion of the plume extends approximately 5,600 feet to the southeast, through Sites 15 and 85, and into Site 14. Site 14, Fire Fighting Training Facility, contributed a small amount of solvent to the 5/15 contaminant plume.

In April 1997, a dual extraction system (DES) began operating at the site as an IRA. The primary objective of this IRA system is to reduce the volume and concentration of hydrocarbon, solvent, and LNAPL contamination in the subsurface soil and groundwater, that poses a threat to human health and the environment. The DES currently consists of 10 dual extraction wells (DEWs), four vapor extraction wells (VEWs), three air sparging wells, a groundwater treatment system rated at 30 gallons per minute (gpm), a soil vapor extraction (SVE) system rated at 550 standard cubic feet per minute (scfm), and a thermal/catalytic oxidation vapor treatment system rated at 1,500 scfm.

The Site 5/15 RPO evaluation required performance of the following tasks:

- Review data to evaluate previously completed site characterization and treatability study activities;
- Prepare site-specific project plans, including the work plan and a site-specific addendum to the project Health and Safety Plan (HASP);

- Evaluate the remedial decision process leading to the current remediation system design, in accordance with the draft RPO handbook;
- Conduct a site visit to further evaluate the effectiveness and efficiency of the existing and currently operating Site 5/15 DES in accordance with the draft RPO handbook;
- Collect analytical data (i.e., for natural attenuation parameters) to support the RPO evaluation;
- Prepare a site-specific RPO report presenting the Parsons ES conclusions regarding the DES's performance, its potential effectiveness in achieving remediation objectives, and recommendations for RPO at Site 5/15;
- Recommend short-term modifications to the future OM&M of the remediation system that will result in future cost savings;
- Identify long-term opportunities for the direction of remedial decision making; and
- Provide an implementation plan for appropriate short-term recommendation and long-term opportunities.

The RPO evaluation determined that the existing SVE system has been efficient at removing contaminant mass from the vadose zone. Through April 1999 (24 months of operation), approximately 38 percent of the estimated total available benzene and trichloroethene (TCE) within the Site 5 source area had been extracted in soil vapors. The liquid- (LNAPL-) recovery system has been less than optimal. Through April 1999, the DES had recovered approximately 0.6 percent of the estimated total volume of LNAPL at Site 5. The technical practicability of the IRA for achieving the cleanup goals within a reasonable timeframe is questionable. The primary benefit of continuing the LNAPL-recovery portion of the IRA is to collect additional data, which can be used to support development of a request for a technical impracticability (TI) waiver for the portion of the plume near the source area.

Under current land-use conditions, no completed exposure pathways to human receptors exist. However, under possible future land-use scenarios, the baseline risk due to contamination in groundwater would be unacceptable to human receptors. Natural attenuation processes are containing the migration of the dissolved petroleum hydrocarbons; however, there is insufficient organic substrate available to support reductive dechlorination of TCE and limit farther migration of the dissolved TCE plume.

Based on the review of the remedial decision process and system performance to date, both short-term recommendations and long-term opportunities were identified to immediately impact system performance and provide a frame-work for the direction of site remediation in the future. Recommendations for short-term system modifications include terminating operation of the liquid-recovery system and reducing the SVE system flow rate by 20 percent. Recommended changes to the monitoring program include eliminating analysis of total volatile petroleum hydrocarbons and total extractable petroleum hydrocarbons in groundwater, reducing the frequency of sampling from semiannual to annual, and reducing the number of groundwater monitoring wells sampled from 56 to 16. If implemented, these short-term recommendations would result in more than \$120,000 in

annual cost savings, which is equivalent to 30 percent of the current annual OM&M budget for the system. Long-term opportunities include pursuing a TI waiver for the Site 5 source area, amending groundwater via organic substrate addition near the downgradient portion of the TCE plume to enhance reductive dechlorination of TCE, and implementing bioslurping technology in the LNAPL plume. Long-term cost savings could be in the millions of dollars. A TI waiver would include development of risk-based cleanup goals for soil and groundwater that would be protective of future human receptors.

Tables ES.1 and ES.2 provide a summary of the potential cost savings associated with the recommendations and opportunities identified as a result of the RPO evaluation of the Site 5/15 IRA. An RPO implementation plan and schedule is included as Section 6 of this document. If so directed by the Contracting Officer, Parsons ES will advise the Base OM&M contractor on implementing the recommendations provided in Section 5 of this document.

TABLE ES.1
RPO SUMMARY: SHORT-TERM RECOMMENDATIONS
 SITE 5/15 CONTAMINANT PLUME
 REMEDIAL PROCESS OPTIMIZATION
 EDWARDS AFB, CALIFORNIA

Short-Term Optimization Recommendations	Annual Cost Savings	Cost Savings Over 30-Year Project Life Cycle ^{a/}	Reduction in Time to Meet Cleanup Goals	Difficulty of Implementation
Terminate operation of Site 5/15 liquid-recovery system	\$97K	\$2.9M	None	Moderate - Requires regulatory approval
Reduce flow rate and vacuum at each active SVE well	b/	b/	None	Low – Requires Base O&M contractor implementation
Cycle among SVE wells	c/	c/	None	Low – Requires Base O&M contractor implementation
Optimize long-term monitoring (see Section 5)	\$70K	\$2.1M	None	Low - Requires regulatory approval

^{a/} Estimated costs given in 1999 dollars (see Section 4).

^{b/} Cost savings included under termination of liquid recovery system.

^{c/} To Be Determined.

TABLE ES.2
RPO SUMMARY: LONG-TERM OPPORTUNITIES
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Long-Term Optimization Opportunities	Annual Cost Savings	Cost Savings Over 30-Year Project Life Cycle ^{a/}	Reduction in Time to Meet Cleanup Goals	Difficulty of Implementation
Develop proposal for TI Waiver – Terminate operation of Site 5/15 remediation system	\$365K	\$10.9M	> 30 years	High – Requires regulatory approval and negotiation of site-specific, risk-based cleanup goals
Establish site-specific, risk-based cleanup goals	b/	b/	TBD	High – Requires regulatory approval
Enhance TCE biodegradation via organic substrate addition. Terminate operation of Site 14 remediation system.	\$125K	\$3.8M	~ 10 years	Moderate – Requires regulatory approval, treatability study, and negotiation of site-specific, risk-based cleanup goals
Implement bioslurping in Site 5 source area	\$150K	\$3.0M ^{c/}	~ 10 % (3 years)	Low - Requires treatability study and capital investment to retrofit extraction wells

^{a/} Costs given in 1999 dollars (see Section 4).

^{b/} To Be Determined.

^{c/} Based on an estimated 20-year period of operation.

SECTION 1

INTRODUCTION

This document was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the United States (US) Air Force Center for Environmental Excellence/Technology Transfer Division (AFCEE/ERT), as part of a delivery order under the US Air Force (USAF) Air Mobility Command (AMC) contract (F11623-94-D0024, RL 72). The primary objective of this project is to evaluate the performance of the remedial system installed at Edwards Air Force Base, Operable Unit 2, South Base, Site 5/15, by using the guidance presented in the Remedial Process Optimization Handbook (Parsons ES, 1999a). The handbook will be used by AFCEE to review the performance of existing remediation systems, implement performance enhancements on existing systems, perform 5-year Record of Decision (ROD) reviews, and prepare documentation for "Operating Properly and Successfully" (OPS) certification. The Air Force goal for the RPO program is to:

1. Assess the effectiveness of the remedial action;
2. Augment the efficiency of the remedial action; and
3. When possible, identify annual operating, maintenance, and monitoring (OM&M) cost savings in excess of 20 percent for each system evaluated.

This site-specific report presents the results of the remedial process optimization (RPO) evaluation conducted at Site 5/15.

1.1 DESCRIPTION OF THE RPO PROCESS

RPO is a systematic approach for evaluating and improving the effectiveness and efficiency of site remediation so that maximum risk reduction is achieved for each dollar spent. Although RPO is associated with the optimization of remediation systems and *how* the cleanup will be completed, it also reviews *why* certain cleanup goals have been established and updates those decisions based on new regulatory options. Just as the technical approach to remediation should be upgraded to take advantage of scientific advances, changes in regulatory framework such as risk-based cleanup goals and the growing acceptance of monitored natural attenuation should be considered in the optimization process. An effective RPO program pursues a wide range of optimization opportunities.

1.2 SCOPE AND OBJECTIVES OF THE EDWARDS AFB RPO EVALUATION

The work plan (Parsons ES, 1999b) outlined the activities to be conducted at Site 5/15 to implement the procedures described in the draft RPO handbook (Parsons ES, 1999a). This effort required the accomplishment of the following tasks:

- Review data to evaluate previously completed site characterization and treatability study activities;
- Prepare site-specific project plans, including the work plan and a site-specific addendum to the project Health and Safety Plan (HASP) (Parsons ES, 1998);
- Evaluate the remedial decision process leading to the current remediation system design, in accordance with the draft RPO handbook;
- Conduct a site visit to evaluate the effectiveness and efficiency of the existing and currently operating Site 5/15 dual extraction system (DES) in accordance with the draft RPO handbook;
- Collect analytical data to support the RPO evaluation; and
- Prepare this site-specific RPO report, containing the Parsons ES conclusions regarding the system performance, its potential effectiveness in achieving remediation objectives, and recommendations for RPO at Site 5/15.

The objectives of the RPO project and the Site 5/15 RPO evaluation include:

- Reviewing and updating the existing conceptual site model (Section 2);
- Evaluating the cleanup goals established for the site (Section 3);
- Examining the effectiveness of the existing remediation system in relation to the performance criteria (Section 4);
- Recommending short-term modifications to the future operation, maintenance, and monitoring (OM&M) of the remediation system that will result in future cost savings (Section 5);
- Evaluating monitored natural attenuation (MNA) as an alternative remedial method.
- Identifying long-term opportunities for the direction of remedial decision making; and
- Providing an implementation plan for appropriate short-term recommendation and long-term opportunities (Section 6).

This report is divided into six sections, including this introduction, and two appendices. A review of the conceptual site model is presented in Section 2. Section 3 provides an evaluation of the cleanup goals. Section 4 presents an evaluation of the remedial system effectiveness. Section 5 presents recommendations for short- and long-term RPO opportunities, and Section 6 provides an RPO implementation plan. Appendix A provides details regarding the calculation of risk-based cleanup standards. Appendix B presents the cost evaluation for operations and maintenance of the remediation system.

1.3 SITE INFORMATION

The site setting, operational history, and previous investigations conducted are reviewed in the following subsections.

1.3.1 Site Description and Operational History

Edwards AFB is located in Kern, Los Angeles, and San Bernadino Counties, California, approximately 60 miles northeast of Los Angeles at the western edge of the Mojave Desert. The original facilities at Site 5/15 were constructed in the early 1940s, when the original Main Base (at Muroc Army Airfield) was located at the area now known as South Base. In the early 1950s, Muroc Army Airfield was renamed Edwards AFB, the Main Base was moved north to its current location, and most activities in the South Base area ceased (Earth Technology Corporation [Earth Tech], 1996a).

Site 5/15 is located in the northern portion of the South Base OU 2, north of the South Base taxiway and runway, and south of the Main Base (instrument) runway (Figure 1.1). Site 5, referred to as the Waste Petroleum, Oils, and Lubricants (POL) Storage Area, consists of three former underground storage tank (UST) clusters: the fuel oil depot, the southern fuel depot, and the waste POL tanks. The USTs had probably been out of service for approximately 30 years at the time of their removal in 1994 (Earth Tech, 1996a). A total of 26 USTs, with capacities ranging from 3,000 to 50,000 gallons, were located within Site 5. From the 1940s until the early 1980s, the USTs were used to store petroleum fuels and lubricants, including waste jet fuels, gasoline, and motor oils. By 1994, all the former fuel USTs had been removed from Site 5. Soil samples collected during tank removal operations indicated that most of the USTs had leaked (Earth Tech, 1996a).

Site 15 consists of the western portion of the Birk Flight Test Center Facility. The site encompasses approximately 100 acres, and is bounded on the south by the northern taxiway of the South Base runway and on the north by C Street. The site's western and eastern boundaries are defined by First and Sixth Streets, respectively (Earth Tech, 1997b). The original facilities at Site 15 consisted of airplane hangars, shops, runway aprons, USTs, and other facilities that were moved or demolished in the 1950s when Base operations were relocated to the Main Base area. In the mid-1980s, the Technical Support Facility (TSF), the Integrated Maintenance Facility (IMF), and the Combined Test Force (CTF), now called the Birk Flight Test Center, were constructed at Site 15 to conduct research and testing activities associated with the B-2 bomber (Earth Tech, 1996a).

1.3.2 Previous Investigations

Characterization and monitoring of petroleum hydrocarbon contamination at Site 5/15 began in 1982. Since 1993, Earth Tech has conducted remedial investigations at Sites 5 and 15, and Potential Release Location (PRL) 85 (Old South Base Fuel Pipeline, now

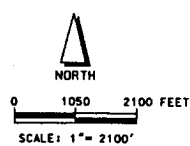
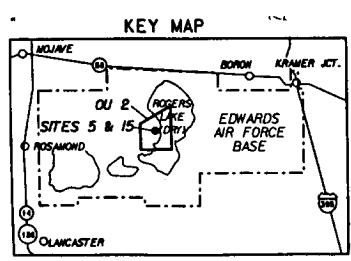
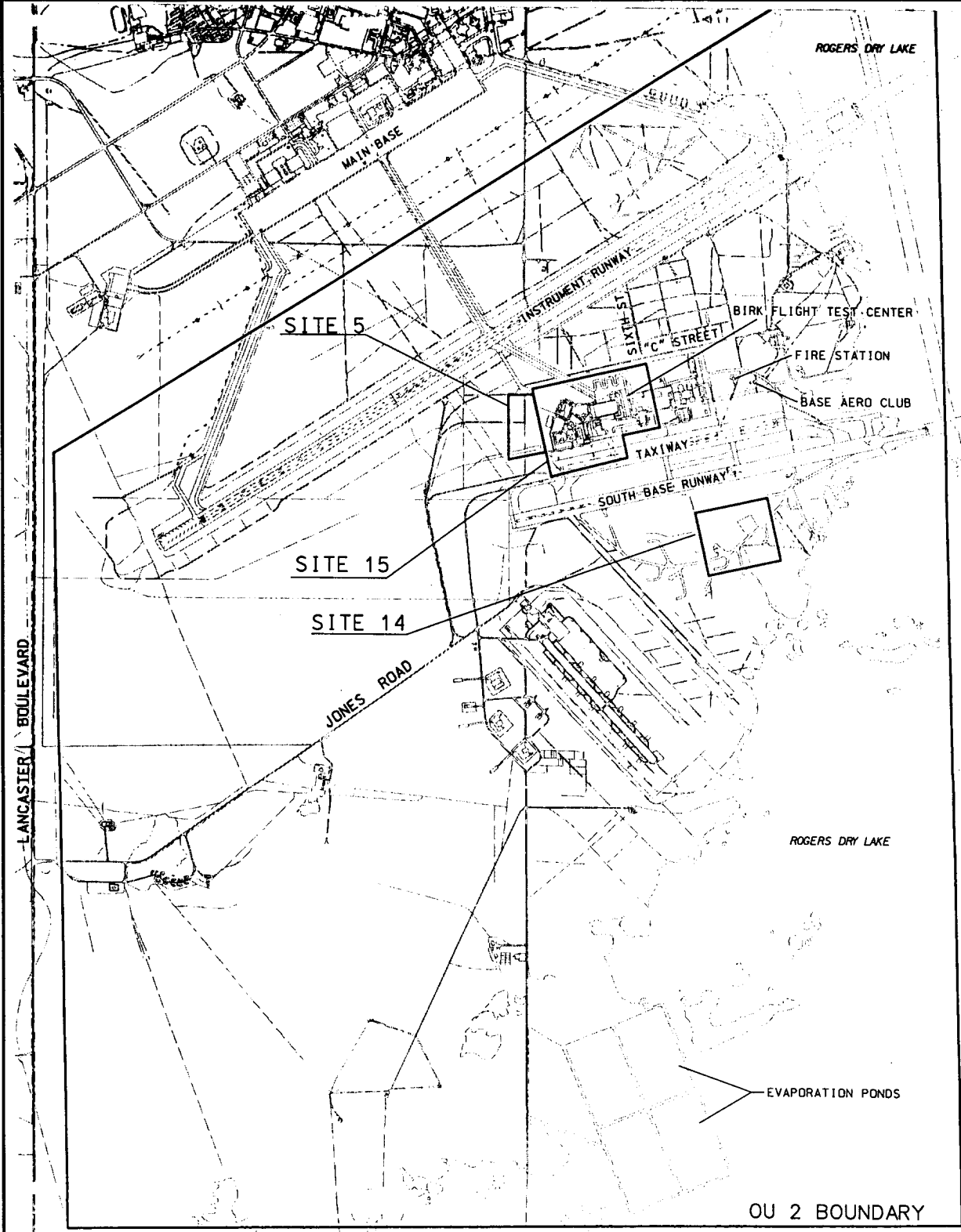


FIGURE 1.1
LOCATION OF SITES 5, 14, AND 15
SOUTH BASE OPERABLE UNIT
 Site 5/15 Contaminant Plume
 Remedial Process Optimization
 Edwards AFB, California
PARSONS
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 Denver, Colorado

called Site 85) under the Installation Restoration Program (IRP) for South Base OU2. The investigative activities and results are discussed in the following reports:

- IRP UST Investigation Summary Reports (Earth Tech, 1996b).
- Site 5 Remedial Investigation/Feasibility Study (RI/FS) Informal Technical Information Report (ITIR) (Earth Tech, 1996c);
- Site 15 RI/FS ITIR (Earth Tech, 1996d); and
- PRL 85 RI/FS ITIR (Earth Tech, 1996e).

In addition, Earth Tech has prepared several documents specific to the remediation of Site 5/15. These documents include:

- Site 5/15 Contaminant Plume Hot-Spot Removal Engineering Evaluation/Cost Analysis (EE/CA) (Earth Tech, 1996a).
- IRP Site 5 Dual Extraction Pilot Test RI/FS ITIR (Earth Tech, 1996f).
- Site 5/15 Contaminant Plume Hot-Spot Removal Action Memorandum (Earth Tech, 1997a).
- Site 5/15 Contaminant Plume Treatability Study Work Plan (TSWP) (Earth Tech, 1997b).
- Site 5/15 Dual Extraction System Operation and Maintenance (O&M) Plan (Earth Tech, 1997d).
- Addendum 1 to the Site 5/15 Contaminant Plume TSWP (Earth Tech, 1998b).
- Preliminary Draft Site 5/15 Contaminant Plume Treatability Study Status Report (September 1996 to April 1998) (Earth Tech, 1998c).
- Draft Quarterly Monitoring Report, May, June, and July 1998, Site 5/15 Dual Extraction System (Earth Tech, 1999a)
- Draft Quarterly Monitoring Report, August, September, and October 1998, Site 5/15 Dual Extraction System (Earth Tech, 1999b)
- Draft Quarterly Monitoring Report, November, December 1998, and January 1999, Site 5/15 Dual Extraction System (Earth Tech, 1999c)
- Draft Quarterly Monitoring Report, February, March, April 1999, Site 5/15 Dual Extraction System (Earth Tech, 1999d)

1.3.3 Site Geology and Hydrogeology

The descriptions of the geology and hydrogeology provided in this section are specific to Site 5/15 at Edwards AFB. Detailed discussions and geologic sections of Sites 5 and 15 are provided in the Site 5/15 Contaminant Plume TSWP (Earth Tech, 1997c).

1.3.3.1 Geology

The geology beneath Site 5/15 consists of unconsolidated alluvial sediments overlying granitic bedrock. The alluvium is characterized by clay, silty clay, sandy clay, silt, clayey sand, and interspersed layers of fine and coarse sand. The amount of clay increases with depth at Site 5, and the fine and coarse sand layers are more continuous toward Site 15. Weathered granitic bedrock occurs at depths of approximately 115 feet below ground surface (bgs) (at 5-MW04) to 143 feet bgs (at 15-M02) (see Figure 1.2 for monitoring wells locations), and dips in a southeasterly direction toward the Rogers Dry Lake.

1.3.3.2 Groundwater

Depth to groundwater in the alluvium varies from approximately 50 to 55 feet bgs. Previously, the groundwater elevation at Site 5 may have been as much as 20 feet higher, as evidenced by the placement of the well screen (25 feet to 116 feet bgs) in the abandoned Base supply well. The approximate direction of groundwater flow is to the east-southeast. The average hydraulic gradient is 0.001 foot per foot (ft/ft) (Earth Tech, 1997c). Figure 1.3 shows the water-table elevations at Site 5/15 based on water level measurements collected in April 1999.

Results from a step-drawdown pump test performed at Site 5 (Earth Tech, 1996f) indicate an average hydraulic conductivity of 23 feet per day (ft/day) (in 5-PW01) for the alluvial aquifer, and a groundwater velocity of 42 feet per year (ft/yr) (assuming an effective porosity of 0.2). It should be stressed that the groundwater velocity does not necessarily equal the actual solute transport velocity between any two points in the aquifer due to factors such as adsorption. The drawdown test was performed for approximately 19 hours (Earth Tech, 1996f).

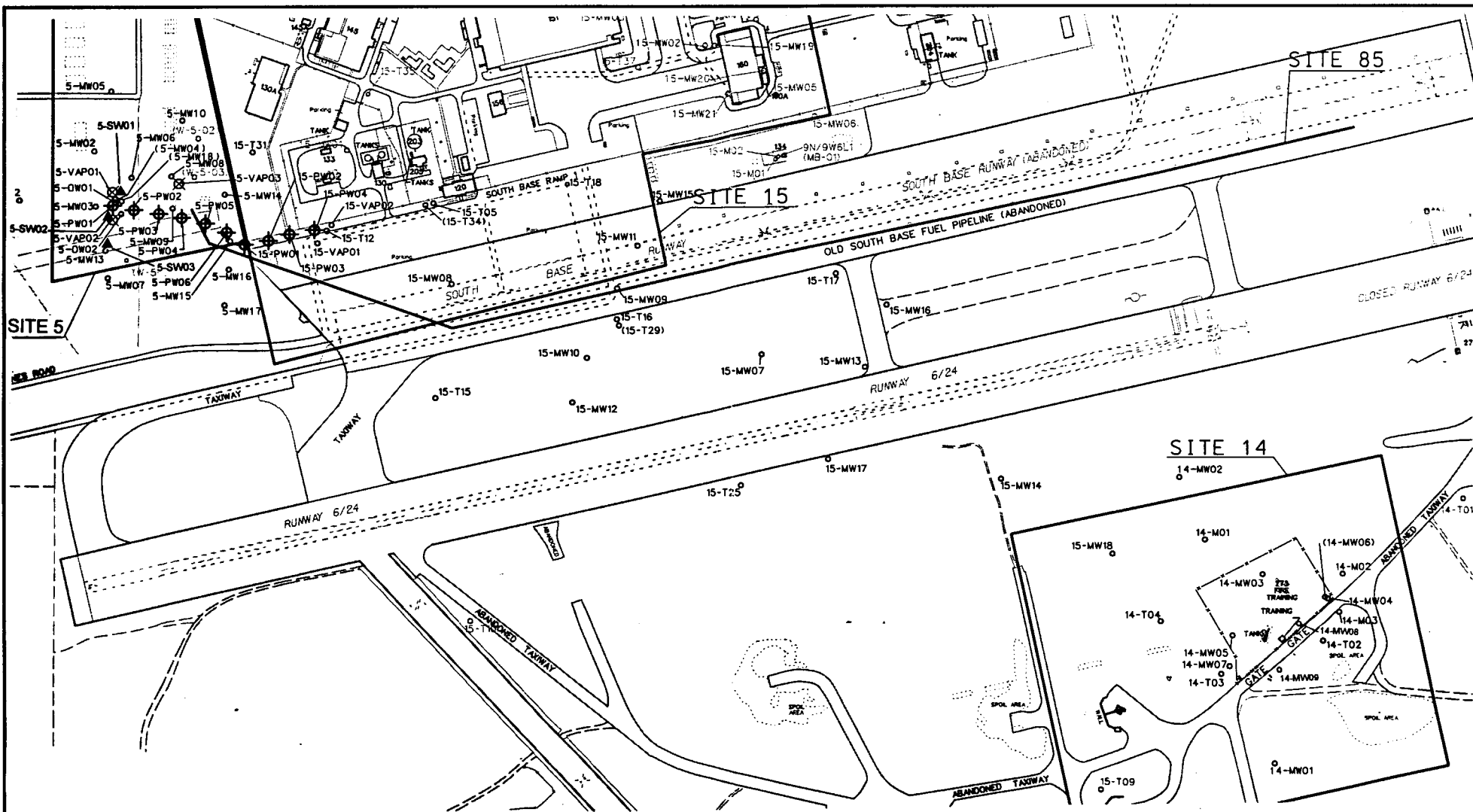
1.3.4 Nature and Extent of Contamination

A description of the nature and extent of soil, groundwater, and free product contamination is provided in the following subsections. The source of site contamination was leaks and spills from fuel USTs and other flightline operations in the 1940s and 1950s.

1.3.4.1 Soils

Benzene, toluene, ethylbenzene, total xylenes (BTEX), and trichloroethene (TCE) are the primary contaminants detected in site soils above the total designated levels (TDLs) (California Regional Water Quality Control Board [CRWQCB] - Central Valley Region, 1989) and the residential preliminary remediation goals (PRGs) (US Environmental Protection Agency [USEPA] Region 9, 1995) (Earth Tech, 1997a). The TDLs were calculated by converting each contaminant's California or federal maximum contaminant level (MCL), whichever is more stringent, from milligrams per liter (mg/L) to milligrams per kilogram (mg/kg) and multiplying by an attenuation factor of 1 and a leachability factor of 10. This procedure follows the methodology outlined by the CRWQCB-Central Valley Region (1989) (Earth Tech, 1997b).

Earth Tech (1997b) delineated the estimated areal extent of volatile organic compound (VOC) contamination in soils exceeding the TDLs based on data collected during the



EXPLANATION

- EXISTING MONITORING WELL
- ⊗ EXISTING DUAL EXTRACTION WELL
- ⊕ EXISTING VAPOR EXTRACTION WELL
- ▲ EXISTING AIR SPARGE WELL
- () WELL SCREEN BELOW WATER TABLE

NOTES:

1. ABANDONED WELL 5-MW11 NOT SHOWN

2. WELLS IN LIGHT SHADE ARE NOT ASSOCIATED WITH THE SITE 5/15 CONTAMINANT PLUME OR ARE NOT BEING MONITORED.

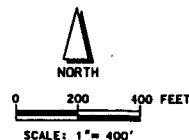
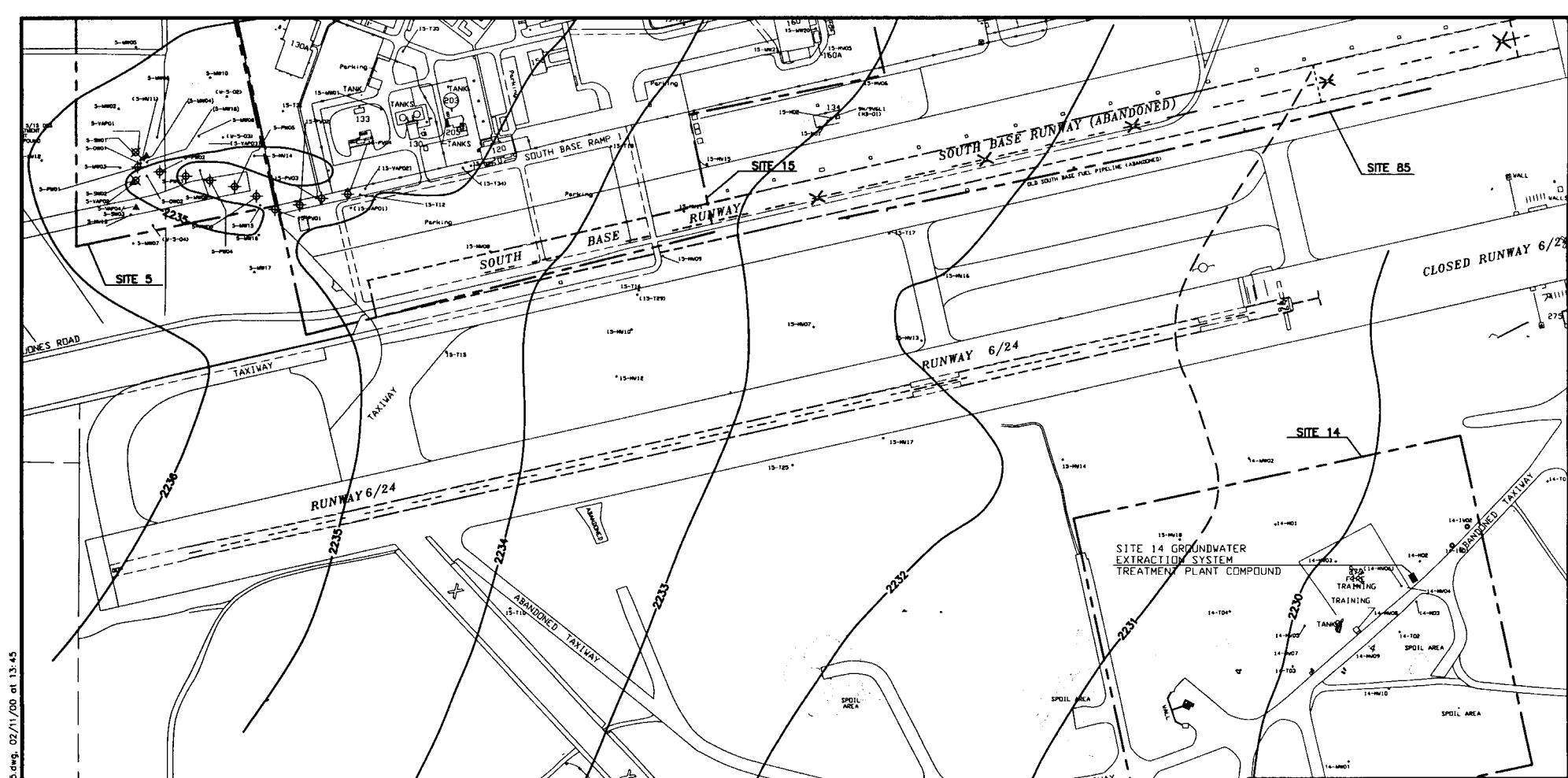


FIGURE 1.2 LOCATION OF MONITORING AND EXTRACTION WELLS

Site 5/15 Contaminant Plume
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LEGEND

- EXISTING MONITORING WELL
- ⊕ EXISTING DUAL EXTRACTION WELL
- ⊗ EXISTING VAPOR EXTRACTION WELL
- ▲ EXISTING AIR SPARGE WELL
- () WELL SCREEN BELOW WATER TABLE

NOTES:

1. ABANDONED WELL 5-MW11 NOT SHOWN.
2. WELLS IN LIGHT SHADE ARE NOT ASSOCIATED WITH THE SITE 5/15 CONTAMINANT PLUME OR ARE NOT BEING MONITORED.

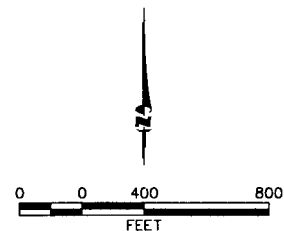


FIGURE 1.3
GROUNDWATER
POTENTIOMETRIC
SURFACE
(APRIL 1999)

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

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RI/FS (Earth Tech, 1996d). The outline of soil TDL exceedances is shown on Plate 1, which is provided at the end of the document following Appendix B. A summary table of the VOC concentrations in soil that exceeded the TDLs is also provided on Plate 1. VOC concentrations exceeding their respective TDLs in soil generally occur at depths between 24 and 50 feet bgs.

1.3.4.2 Groundwater

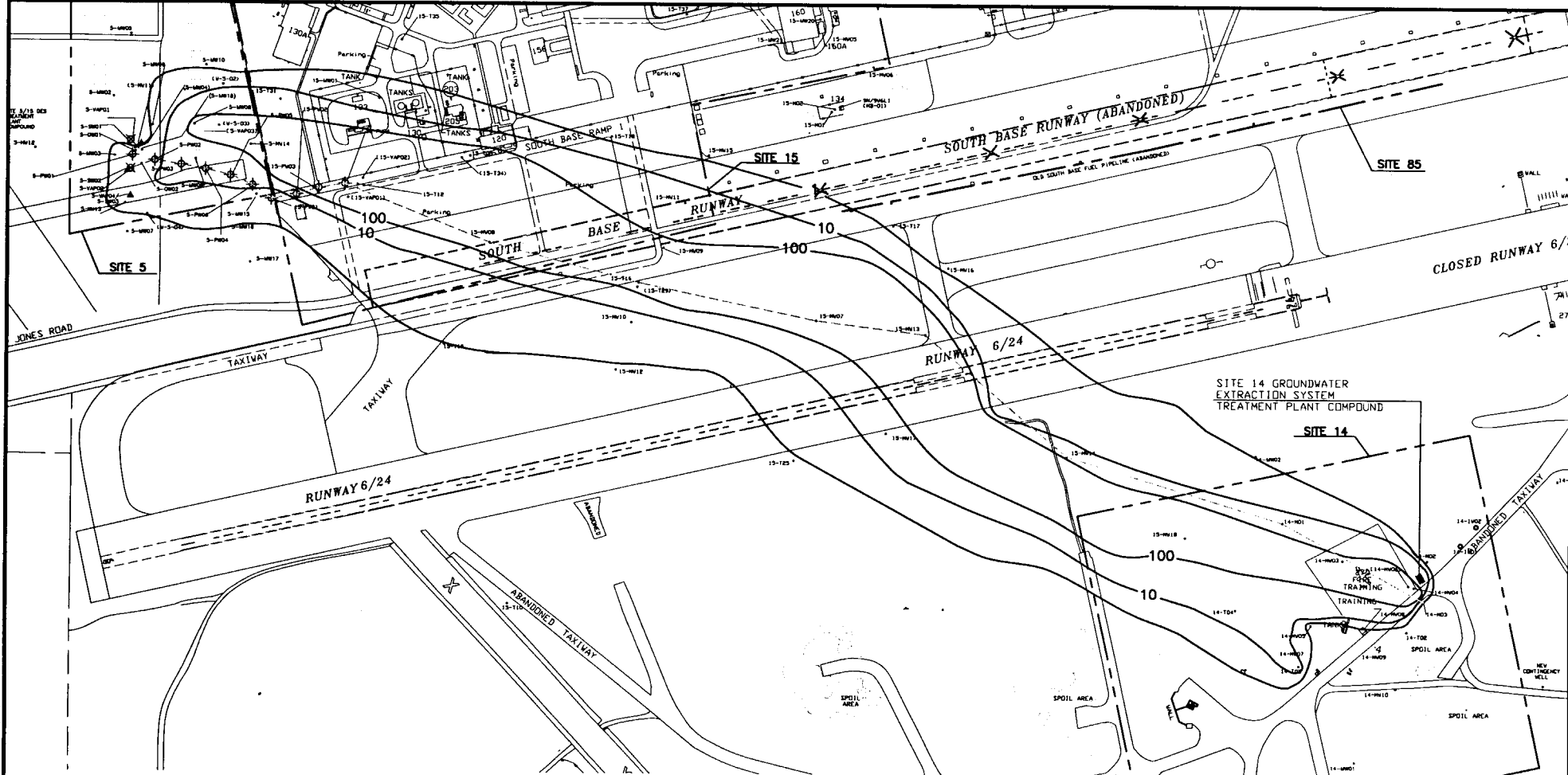
The Site 5/15 contaminant plume identified in the RI/FS appears to originate in the area underlying the former waste POL tanks at Site 5/15. Plate 1, reproduced here from the TSWP (Earth Tech 1997c), shows the known lateral extent of the groundwater contaminant plume at Site 5/15 prior to implementation of the interim removal action (IRA) (January 1996). A summary table of the groundwater contaminant concentrations exceeding the MCLs also is provided on Plate 1. The dissolved fuel and solvent plume has migrated in the direction of regional groundwater flow (southeast) at least 3,500 feet (Figure 1.4), and the TCE plume extends approximately 5,600 feet to the southeast, into Site 14 (Figure 1.5). The chemicals of potential concern (COPCs) in groundwater at Site 5/15 were determined by comparing the concentrations of contaminants in groundwater with their respective California or Federal MCLs (Earth Tech, 1997b). Groundwater contaminants exceeding MCLs (California Department of Health Services [CDHS], 1994) include benzene, toluene, xylenes, 1,1,1-trichloroethane (1,1,1-TCA), TCE, methylene chloride, and ethylene dibromide (EDB). Maximum groundwater concentrations of benzene and TCE have been detected at 3,600 and 2,500 micrograms per liter ($\mu\text{g/L}$), respectively (Earth Tech, 1997a).

1.3.4.3 Free Product

Floating free-phase product (light nonaqueous-phase liquid [LNAPL]) exists along much of the length of the groundwater plume and occurs within the area of groundwater contamination exceeding the MCLs. Probable sources of free product are the waste POL area and former southern fuel depot (Site 5) and the old South Base fuel pipeline (Site 85). The mobile LNAPL includes unknown volatile hydrocarbons, JP-4, BTEX, other aromatic hydrocarbons, naphthalene, and TCE (Earth Tech, 1997c). In November 1996, the static product thickness ranged from 0.11 foot (15-MW07) to 3.04 feet (5-MW09) (Earth Tech, 1997c). The product thickness measured in April 1999 ranged from 0.10 foot (5-MW13) to 9.10 feet (5-PW05). Based on mobile LNAPL thicknesses measured in October 1995 and January 1996 and the observed areal extent of contamination, an estimated 148,000 gallons of product may be floating on the water table within the boundary of Site 5 alone. An estimated 599,000 gallons of product may be present on the water table throughout the Site 5/15 Contaminant Plume (Earth Tech, 1997c). Earth Tech (1999e) now believes the length of the free product plume may be much larger than previously interpreted.

1.3.5 Remediation System Description

A non-time-critical removal action was proposed by Edwards AFB in 1996 to address soil and groundwater contamination specifically at the hot-spot beneath Site 5 in an effort to reduce long-term groundwater degradation downgradient of the site. Specific objectives of the IRA are detailed in Section 4.1. Vapor extraction in the vadose zone and simultaneous extraction of LNAPLs and groundwater were considered to be the only



LEGEND

- EXISTING MONITORING WELL
- ⊕ EXISTING DUAL EXTRACTION WELL
- ⊗ EXISTING VAPOR EXTRACTION WELL
- ▲ EXISTING AIR SPARGE WELL
- () WELL SCREEN BELOW WATER TABLE
- 10' CONCENTRATION CONTOUR (ug/L)

NOTES:

1. ABANDONED WELL 5-MW11 NOT SHOWN.
2. WELLS IN LIGHT SHADE ARE NOT ASSOCIATED WITH THE SITE 5/15 CONTAMINANT PLUME OR ARE NOT BEING MONITORED.

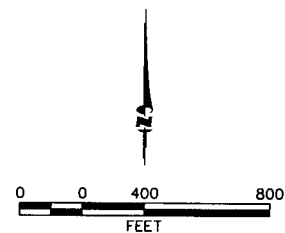


FIGURE 1.5

**TRICHLOROETHENE (TCE)
IN GROUNDWATER
(APRIL 1999)**

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

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viable technologies to address the gross contamination (Earth Tech, 1996a). Therefore, a pilot-scale DES was proposed for installation and operation at Site 5.

Startup of the pilot-scale DES commenced on April 10, 1997. The system was shutdown on April 11, 1997, and following several system adjustments, the DES was restarted on April 21, 1997. For reporting purposes, continuous operation of the DES is considered to have started on April 21, 1997 (Earth Tech, 1998c). The DES currently consists of the following components:

- Ten dual extraction wells (DEWs) (5-PW01 through 5-PW06 and 15-PW01 through 15-PW04);
- Four vapor extraction wells (VEWs) (5-VAP01 through 5-VAP04);
- Three air sparging wells (5-SW01 through 5-SW03);
- A groundwater treatment system rated at 30 gallons per minute (gpm);
- An soil vapor extraction (SVE) system rated at 550 standard cubic feet per minute (scfm); and
- A thermal/catalytic oxidation vapor treatment system rated at 1,500 scfm.

The DES is an IRA and is designed to remove contaminant mass from the vadose zone and floating free-phase product (LNAPL) near Site 5. The following description of the DES process flow is illustrated on Figure 1.6 and was taken from the Treatability Study Status Report (TSSR) (Earth Tech, 1998c). The locations of the extraction wells are shown on Figure 1.2. Additional system details are presented in the O&M plan (Earth Tech, 1997d).

1.3.5.1 Product Recovery, Groundwater Extraction, and Treatment System

Groundwater and mobile LNAPL are extracted from the DEWs using top-loading pneumatic pumps. An air compressor (AC-6000 on Figure 1.6) supplies compressed air that operates the pneumatic pumps. The extracted groundwater and product discharge into an oil (fuel)/water separator (OWS-2000) located at the treatment plant. Separated fuel drains from OWS-2000 into an aboveground product storage tank (AST-2100). The groundwater drains into an equalization tank (T-3000). An air stripper feed pump (P-3100) pumps groundwater from the equalization tank through a float-controlled throttling valve (FCV-3000), then through an in-line filter (F-3200) and into a Low-Profile Air Stripper (LPAS) (AS-3300). Under normal operating conditions, the throttling valve restricts the flow of groundwater from the equalization tank into the LPAS so that it is equal to the groundwater extraction flow rate, thus maximizing the stripping efficiency in the LPAS. The in-line filter removes suspended solids from the process flow stream.

Organic contaminants are stripped (i.e., removed) from the groundwater in the LPAS. The LPAS blower (B-3600) draws ambient air through the stripper, countercurrent to the groundwater flow. Treated groundwater collects in the LPAS sump, where it is pumped by LPAS sump pump (P-3400) to the granular activated carbon (GAC) system. The

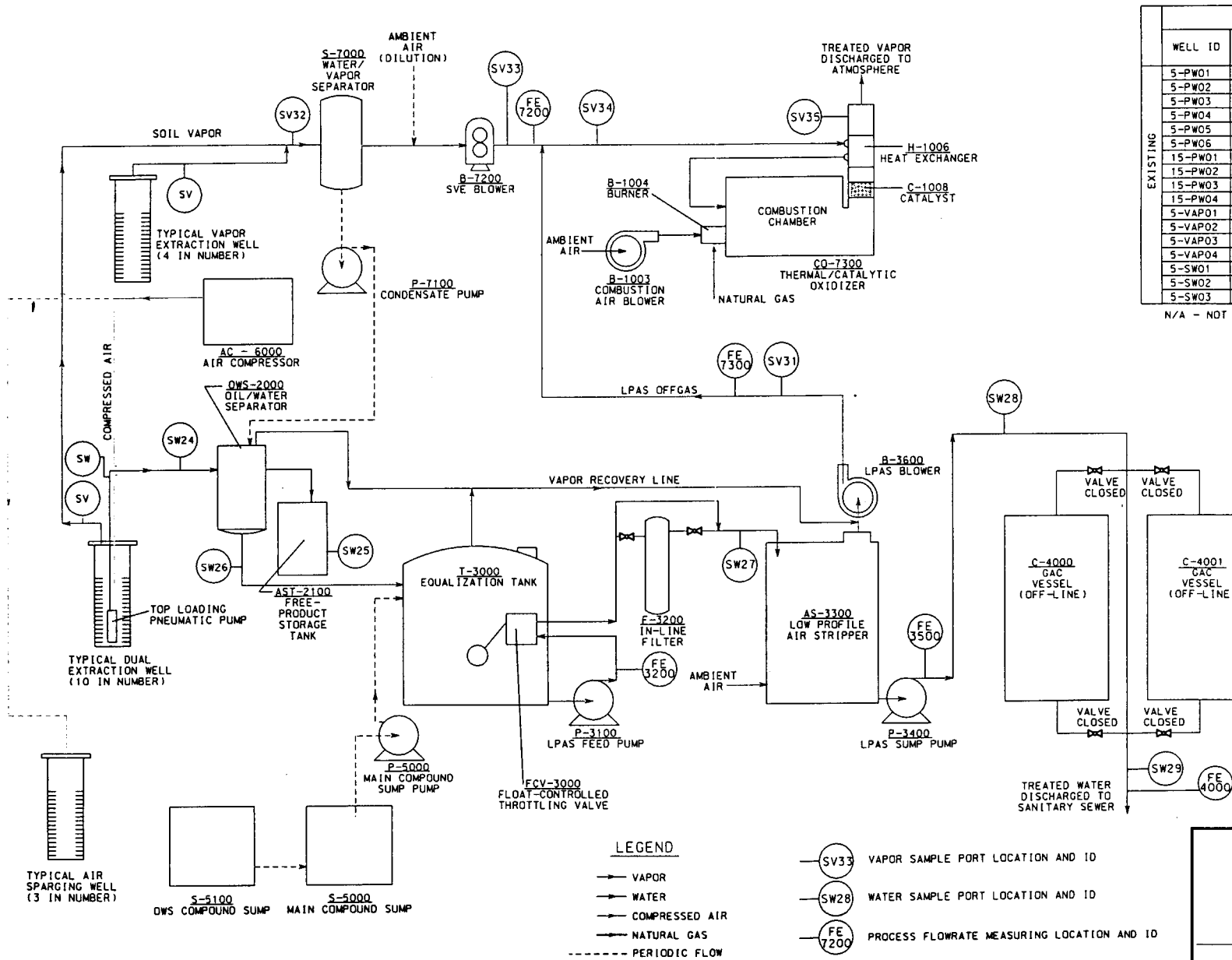


FIGURE 1.6
SIMPLIFIED PROCESS
FLOW DIAGRAM
 Site 5/15 Contaminant Plume
 Remedial Process Optimization
 Edwards AFB, California

GAC system consists of two GAC vessels that can be operated in series, in parallel, or bypassed. Initially the vessels were operated in series, then in parallel, then each one separately, and finally bypassed (as shown on Figure 1.6). When on line, the carbon adsorbs residual organic contaminants from the groundwater. Treated groundwater is discharged to the sanitary sewer. Vapors from the oil/water separator and the equalization tank are drawn through the LPAS blower, along with the LPAS off gas, and discharged to the vapor treatment system (CO-7300).

1.3.5.2 Soil Vapor Extraction and Treatment System

Soil vapors are extracted from the 10 DEWs and the four VEWs under a vacuum generated by SVE blower B-7200 (Figure 1.6). The extracted soil vapor passes through a water/vapor separator (S-7000) to remove entrained water, free product, and solids. The condensate (i.e., water and product) is pumped by condensate pump P-7100 to the OWS-2000, though initially the condensate was pumped to the equalization tank. Dilution air, if required, is combined with the extracted soil vapor and drawn through the SVE blower. The soil vapor discharged from the SVE blower is combined with the LPAS off gas discharged from the LPAS blower. The combined vapor flow is preheated in a heat exchanger (H-1006), then passes through a flame arrestor and is discharged into the thermal/catalytic oxidizer (CO-7300). Natural gas and ambient air from combustion blower B-1003 are mixed and ignited in a burner (B-1004) to maintain the oxidizer at the operating temperature. The vapors are thoroughly mixed and heated in the combustion chamber. In thermal mode, the contaminants are oxidized in the combustion chamber at a minimum temperature of 1,450 degrees Fahrenheit (°F). In catalytic mode, the combustion chamber acts as a preheat chamber, the vapors are heated to a minimum 800°F and are then passed through the catalyst where the contaminants are oxidized. The treated vapor stream is discharged to the atmosphere.

1.3.5.3 Air Sparging System

The Site 5/15 DES was expanded in January 1999 with the addition of three air sparging wells. The objectives of the expansion were to enhance the remediation of contaminated soils and groundwater in the Site 5/15 contaminant plume hot spot and to evaluate the benefits and limitations of air sparging, in conjunction with SVE, in remediating the Site 5/15 contaminant plume (Earth Tech, 1997a, 1997b, and 1998c). The system expansion consisted of installing the following components (see Figure 1.6) (Earth Tech, 1998b):

- Two air sparging wells (5-SW01 and 5-SW02);
- One nested air sparging well/VEW (5-SW03/5-VAP04);
- Soil vapor and compressed air piping; and
- Instrumentation and controls.

The air sparging system was integrated into the existing Site 5/15 DES and pilot-tested (less than 24-hour period) in January 1999 (Earth Tech, 1999c). Longer-term pilot testing was recommended and is scheduled to be implemented in September 1999 (Earth Tech, 1999d). Currently, the air sparging system is not operational.

1.3.5.4 Site 14 Groundwater Extraction and Treatment System

Site 14, the South Base Fire Fighting Training Area, is located approximately 500 feet south of the South Base runway and southeast of (downgradient from) Site 5/15 (Figure 1.1). Site 14 is approximately 2.5 miles upgradient from the South Base well field, which supplies a portion of Edwards AFB's water for domestic, irrigation, and industrial uses (Earth Tech, 1998a).

Based on the current delineation of the Site 5/15 contaminant plume, it is believed that the TCE plume underlying Site 14 is largely an extension of the Site 5/15 contaminant plume (Earth Tech, 1998a). TCE has been the most widely detected organic contaminant exceeding its groundwater MCL at Site 14. In June 1998, the highest TCE concentration (340 µg/L) was observed in well 15-MW18 (Figure 1.2). No mobile LNAPL has been observed at Site 14. Concentrations of solvents that are less than one percent of the compounds solubility are not suspected to occur as a DNAPL. The solubility of TCE is 1,100 mg/L, and the maximum detected concentration of 340 µg/L is an order of magnitude less than 1,100 µg/L (one percent of the TCE solubility).

In July 1998, a Treatability Study Work Plan (TSWP) was completed to implement a treatability study at Site 14 (Earth Tech, 1998a). The primary objective of the treatability study was to test groundwater extraction as a remedial action to limit further downgradient migration of the Site 5/15 contaminant plume, and to reduce contaminant mass (Earth Tech, 1998a). On December 1, 1998, a groundwater extraction and treatment system began operating at Site 14. The system consists of four groundwater extraction wells (two existing monitoring wells [14-MW04 and 14-MW07] and two newly-installed monitoring wells [14-MW08 and 14-MW09]), a GAC treatment system, and two reinjection wells.

1.3.6 Monitoring Program Description

1.3.6.1 Media Monitoring

The objective of the media monitoring program is to document changes in the free product thickness, to document changes in the vapor and groundwater contaminant concentrations, and to monitor changes in the lateral extent of contamination. Currently, groundwater is sampled from fourteen wells at Site 14, eighteen wells at Site 15, and fourteen wells at Site 5 on a semiannual basis. The groundwater is analyzed for VOCs (Method SW8260B), volatile hydrocarbons (Method SW8015VB), diesel-range hydrocarbons (Method SW8015DB), and EDB (Method E504.41).

1.3.6.2 System Monitoring

A system monitoring program has been implemented to evaluate the performance of the Site 5/15 DES. The objectives of this monitoring program are to (Earth Tech, 1997d):

- Document compliance with air and water discharge requirements;
- Assess the effectiveness of the DES in remediating soil and groundwater in the Site 5/15 contaminant plume;
- Document contaminant mass removal rates and total mass removed;

- Estimate the groundwater capture zone and effective vapor radii of influence for individual extraction wells and the combined DES well field;
- Determine the process parameters for optimum system performance; and
- Document O&M concerns or problems that may affect long-term reliability and operating costs.

The sampling frequencies for the extraction and monitoring wells during the operation of the DES are shown in Table 1.1 and for the treatment system in Table 1.2. Per the O&M plan (Earth Tech, 1997d), if site conditions change significantly, then sampling frequencies may be altered.

TABLE 1.1
SUMMARY OF WELL MONITORING AND SAMPLING PROGRAM
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Well ID	Groundwater ^{a/}		Vapor ^{b/}		
	Water Level, Free Product Thickness, Flow Rate Measurements	VOCs, EDB, TEPH, and TVPH	Vacuum Measurements	Vapor Concentration (FID) and Flow Rate Measurements	VOCs and TVH
5-PW01	A ^{c/}	B ^{d/}	D ^{e/}	D	E ^{f/}
5-PW02	A	B	D	D	E
5-PW03	A	B	D	D	E
5-PW04	A	B	D	D	E
5-PW05	A	B	D	D	E
5-PW06	A	B	D	D	E
15-PW01	A	B	D	D	E
15-PW02	A	B	D	D	E
15-PW03	A	B	D	D	E
15-PW04	A	B	D	D	E
5-VAP01			F ^{g/}	D	E
5-VAP02			F	D	E
5-VAP03			F	D	E
5-OW01	C ^{h/}	B	F		
5-OW02	C	B	F		
5-MW02	C	B	F		
5-MW03	C	B	F		
5-MW04	C	B	F		
5-MW06	C	B	F		
5-MW08	C	B	F		
5-MW09	C	B	F		
5-MW10	C	B	F		
5-MW13	C	B	F		
5-MW14	C	B	F		
5-MW15	C	B	F		
5-MW16	C	B	F		
5-MW17	C	B			
5-MW18	C	B			
15-VAP01			F		
15-VAP02			F		
15-MW07	C	B			
15-MW08	C	B			
15-MW09	C	B			
15-MW10	C	B			
15-MW11	C	B			
15-MW12	C	B			
15-MW13	C	B			
15-MW14	C	B			
15-MW15	C	B			
15-MW16	C	B			

TABLE 1.1 (Continued)
SUMMARY OF WELL MONITORING AND SAMPLING PROGRAM
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CA

Well ID	Groundwater ^{a/}		Vapor ^{b/}		
	Water Level, Free Product Thickness, Flow Rate Measurements	VOCs, EDB, TEPH, and TVPH	Vacuum Measurements	Vapor Concentration (FID) and Flow Rate Measurements	VOCs and TVH
15-MW17	C	B			
15-MW18	C	B			
15-T05	C	B			
15-T12	A	B	F		
15-T16	C	B			
15-T29	C	B			
15-T31	C	B			
15-T34	C	B			

Source: Earth Tech, 1997d.

a/ Analytical methods for groundwater samples: SW5030/SW8260 (VOCs), SW5030/LUFT MOD 8015 (TVPH), SW3510/LUFT MOD 8015 (TEPH), and E504 (EDB). EDB = Ethylene dibromide; VOCs = Volatile Organic Compounds; TEPH = Total Extractable Petroleum Hydrocarbons; TVH = Total Volatile Hydrocarbons; TVPH = Total Volatile Petroleum Hydrocarbons.

b/ Analytical methods for soil vapor samples: TO-14 (VOCs) and TO-3 (TVH). FID = Flame Ionization Detector.

c/ A = Water level and free product measurements prior to startup (static), daily following startup until extraction system stabilizes, weekly for following month, and monthly thereafter.

d/ B = Water samples collected at or prior to startup and semiannually thereafter.

e/ D = FID, vacuum, and flow rate measurements made at startup, daily following startup until extraction system stabilizes, weekly for following month, and monthly thereafter; TO-14 semiannually after startup

f/ E = TO-14 and TO-3 collected at startup; TO-3 monthly until vapor concentrations stabilize, quarterly thereafter;

g/ F = Vacuum measurements monthly following startup.

h/ C = Water level and free product measurements prior to startup (static) and monthly following startup.

TABLE 1.2
SUMMARY OF TREATMENT PLANT SAMPLING PROGRAM
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Medium	Objectives	Location ^{a/}	Analyses ^{b/}	Frequency
Groundwater	Calculate contaminant mass removal rate and total mass removed in dissolved phase. Evaluate performance of air stripper and loading to lead carbon vessel.	Sample Ports SW27 (air stripper inlet) and SW28 (air stripper outlet/lead carbon vessel inlet)	VOCs, EDB, TVPH, and TEPH	Sample Port SW27: Daily for first two days of operation and monthly thereafter. Sample Port SW28: Daily for first two days of operation and monthly thereafter.
	Evaluate and monitor performance of lead liquid phase carbon unit. Verify treatment plant compliance with effluent requirements.	Sample Port SW29 (Lead carbon vessel outlet/lag carbon vessel inlet)	VOCs, SVOCs, EDB, TVPH, and TEPH	Daily for first two days of operation, weekly for the following 3 weeks and biweekly thereafter. SVOCs first day of operation and quarterly thereafter.
	Verify treatment plant compliance with effluent requirements as needed.	Sample Port SW30 (Lag carbon vessel outlet)	VOCs, SVOCs, EDB, TVPH, and TEPH (as needed)	Sample collected only if contaminants detected at sample port SW29. Analysis limited to contaminant(s) detected at sample port SW29.
	Monitor general water quality parameters in treated effluent being discharged to sanitary sewer.	Sample Port SW30 (Lag carbon vessel outlet)	Common Anions, TDS, Fluoride, Metals (ICP Screen)	First day of operation and quarterly thereafter.
Soil Vapor	Calculate contaminant mass removal rate and total mass removed in vapor phase.	Sample Port SV33	Flame Ionization Detector	Daily for first week of operation, weekly thereafter.
			TO-14 VOCs TO-3 Total Volatile Hydrocarbons	Once during first week of operation and quarterly thereafter.

TABLE 1.2 (Continued)
SUMMARY OF TREATMENT PLANT SAMPLING PROGRAM
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Medium	Objectives	Location	Analyses	Frequency
Soil Vapor (Cont.)	Verify compliance with Kern County Air Pollution Control District requirements.	Sample Port SV34 and SV35 (Oxidizer inlet and Oxidizer outlet)	Flame Ionization Detector TO-14 VOC TO-3 Total Volatile Hydrocarbons	Daily for first week of operation, weekly thereafter. Once during first week of operation and quarterly thereafter.
Carbon	Evaluate organic loading on carbon for disposal.	Grab sample from carbon vessel	SW1311/SW8260 (VOCs in Extract)	Once every two years. Composite sample of carbon during changeout.
Filter Bags	Evaluate organic loading on spent bags for appropriate disposal.	Inline filter bags	SW1311/SW8260 (VOCs in Extract)	Once. Composite sample of first ten spent filter bags.

Source: Earth Tech, 1997d.

a/ See Process Flow Diagram for Sample Port Locations (Figure 2.4).

b/ Common Anions = Chloride, Sulfate, Nitrate (E300.0); EDB = Ethylene dibromide (SW5030/E504); Fluoride (E340.2); Metals ICP Screen (SW 3005/SW6010); SVOCs = Semivolatile Organic Compounds (SW3510/SW8270); TDS = Total Dissolved Solids (E160.1); TEPH = Total Extractable Petroleum Hydrocarbons (SW3510/LUFT MOD 8015); TVPH = Total Volatile Petroleum Compounds (SW5030/LUFT MOD 8015); and VOCs = Volatile Organic Compounds (SW5030/SW8260).

SECTION 2

REVIEW OF CONCEPTUAL SITE MODEL

A conceptual site model (CSM) provides a visual summary of the physical and chemical characteristics of a site. This is the baseline for which personnel responsible for the site can make informed evaluation and remedial decisions. The CSM should be continually updated based on the most recent operating and monitoring data. This section provides an overview of the CSM as previously interpreted and updates it based on any new data available.

2.1 SOURCE OF CONTAMINATION

The CSM for Site 5/15, depicted on Figure 2.1, is based on the site history, hydrogeology, and nature and extent of contamination discussed in Section 1. The CSM indicates approximately 115 feet of fine-grained alluvial sediments (clay, silty clay, sandy clay, silt, clayey sand, and interspersed layers of fine and coarse sand) at Site 5/15 overlying weathered granitic bedrock. The thickness of alluvium increases to approximately 170 feet at Site 14. Groundwater occurs at a depth of approximately 50 to 55 feet below ground surface (bgs). The groundwater flow direction is to the east-southeast at an average hydraulic gradient of 0.00125 (ft/ft) (Earth Tech, 1997b). Figure 1.3 shows the water table elevations at Site 5/15 as measured in April 1999.

The suspected source area shown on the CSM is at Site 5. Formerly, three UST clusters, including the waste POL tanks, the fuel oil depot, and the southern fuel depot were located at Site 5. The site was referred to as the Waste POL Storage Area. Waste solvents were also stored and possibly leaked or were disposed of in the area.

2.2 CONTAMINANT MIGRATION

Because the Site 5/15 LNAPL, groundwater, and soil contamination occur in the subsurface, only subsurface migration pathways are discussed here. Subsurface contaminant migration pathways include leaching of contamination from source area soils and then downward transport through the vadose zone to the saturated zone. Once contaminants reach the groundwater, lateral/vertical migration of dissolved constituents occurs by advection and dispersion through the alluvial aquifer. A hydrocarbon/solvent LNAPL plume has accumulated on the water table and is migrating downgradient at the capillary fringe above the water table. The extent of the dissolved BTEX plume appears to be associated with the extent of the free product plume, and the free product is a continuing source of contamination to the groundwater. The association of the BTEX plume to the free product plume explains the difference from the normally expected BTEX plume length of no more than about 250 feet observed in 90% of the 271 UST cases studied in California (Lawrence Livermore National Laboratory, 1995).

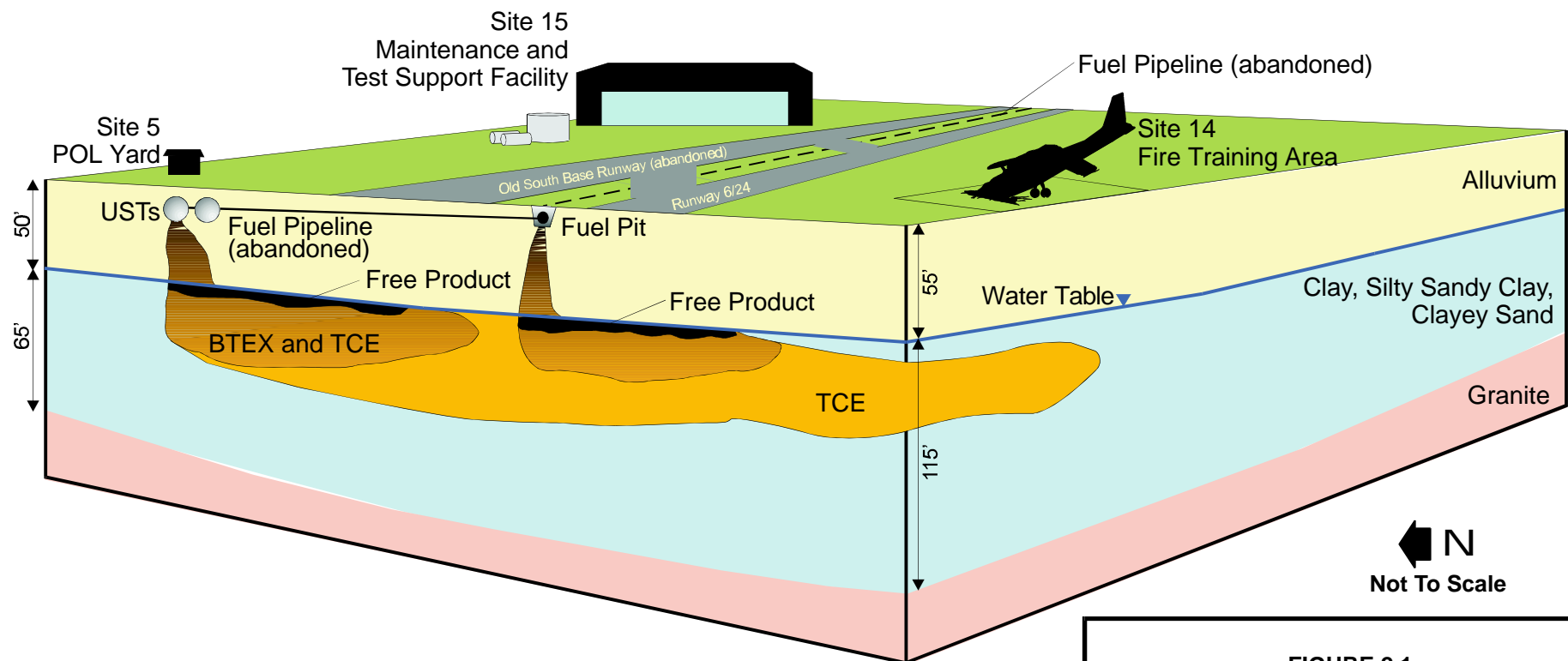


FIGURE 2.1

CONCEPTUAL SITE MODEL

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

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Denver, Colorado

Figures 1.4 and 1.5 show the lateral extent of the benzene and LNAPL, and TCE plumes, respectively, based on groundwater samples collected in April 1999. These two compounds were selected for mapping because they are the primary COPCs with concentrations that exceed their federal MCLs.

Based on the current length of the benzene plume (approximately 3,400 feet), and assuming that contamination reached the water table within 5 years of operation startup (1942) at the former waste POL storage area, the minimum velocity of contaminant migration is 65 ft/yr (0.18 ft/day). The TCE plume is longer (5,600 feet), and indicates a minimum transport velocity of 108 ft/yr (0.3 ft/day). The estimated velocity could be much faster if the contaminant mass did not reach the groundwater until later, thereby allowing a shorter time for the contaminants to migrate the same distance. These observed apparent travel rates are in the range of the groundwater flow rates calculated by Earth Tech (1996f) of 42 feet per year. If the plume is not continuous and occurs as a result of separate sources along the length of the plume, then the separate plume lengths are shorter and more recent source loading to the aquifer could have resulted in the observed plume dimensions.

2.2.1 Trends of Contaminant Concentrations in Groundwater

2.2.1.1 Trend of Concentration versus Distance from the Source.

The first step to evaluate the contaminant plumes at the site was to compare contaminant concentrations at selected sampling locations along the length of the plume at a specific point in time. The purpose of this comparison was to assess if the influx of contamination from the source area has ceased, and the contaminant concentrations are decreasing, and/or if a contaminant slug is passing as a pulse at some point farther downgradient from the source. Also, this comparison may identify if there are other potential source areas contributing to the contaminant plume. The April 1999 analytical results for COPCs at wells along the plume flow line (Earth Tech, 1999d) are listed in Table 2.1.

Figure 2.2 shows a graph of the concentrations of BTEX constituents determined from the April 1999 sampling event versus distance downgradient from the source area at Site 5/15. The BTEX plume is characterized by higher total xylenes concentrations and lower levels of benzene, which is typical of “weathered” fuel, or mid-range distillates such as jet fuel. There is a general decrease in BTEX concentrations over the first 700 feet downgradient from the source, and then a dramatic spike in concentration at 770 feet downgradient (at sampling location 15-PW03). This spike may be the result of a contaminant slug migrating downgradient. A second spike occurs at 3,200 feet downgradient from Site 5 at sampling location 15-MW13, near the distal end of the benzene and free product plumes. This spike may indicate a contribution from a different source area, possibly the former Fuel Pit No. 1, located along the Old South Base Fuel Pipeline (Site 85), approximately 400 feet west-northwest of sampling location 15-T16 (Figure 1.4).

The longitudinal distribution of halogenated solvents from the Site 5/15 source area is shown on Figure 2.3. TCE spikes occur at 450 feet and at 773 feet downgradient from the source. The TCE spike at 773 feet coincides with the 15-PW03 BTEX spike, which was interpreted to be a source-load slug. The *cis*-1,2-DCE increase at this location is

TABLE 2.1
CONCENTRATION versus DISTANCE FROM SOURCE
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Contaminant of Potential Concern				PCE ^{b/}	TCE ^{c/}	cis-DCE ^{d/}	1,1-DCE ^{e/}	EDB ^{f/}	Benzene	Toluene	Ethylbenzene	Xylenes
United States EPA Maximum Contaminant Level				5	5	70	7	0.05	5	1,000	700	10,000
California EPA Maximum Contaminant Level				5	5	60	6	0.02	1	100	680	1,700
LOCID	Scrn Interval	Smpl Depth	Distance ^{a/}									
5-PW01	46-66	~61	0	0	8.6	7.6	0	0.2	0	20	0	340
5-PW02	48-68	~63	98	1.1	6.9	0.75	0.42	103	16	17	4.1	43
5-PW03	49-69	~64	203	2.3	36	4.4	0.7	0.92	19	72	24	219
5-PW04	47-67	~62	299	1.3	28	3.1	0	0.29	8.9	23	10	102
5-PW05	47-67	~62	397	3.3	29	4.4	0	0.53	21	44	15	202
5-MW14	45-65	62.4	450	0.6	450	1.5	0.68	0	16	8.2	18	55
5-PW06	47-67	~62	496	0	15	1	0	0	1.3	3.3	3.5	34.5
15-PW01	46-66	~61	596	0	0	24	0	0	0	4.9	2.9	68
15-PW02	44.4-64.4	~59	680	0	53	0	0	0	0	0	0	0
15-PW03	46-66	~61	773	0	110	56	0	0.23	170	210	570	1,810
15-PW04	44.5-64.5	`59	874	0.23	440	4.2	3	0	29	0.35	0.34	9.4
15-MW08	45-65	59.7	1450	0	271	0.678	0	0	2.04	0	0	0
15-T16	45-60.5	58.7	2160	0	138	0	0	0	0	0	71.4	0
15-MW07	44-59	56.2	2780	0	500	1.3	0	0	4.6	0.5	3.6	95
15-MW13	45-65	62.5	3230	0	650	0	0	0	0	94	63	620
15-MW14	45-65	62.5	3900	0	97.8	0	0	0	0	0	0	0
14-M01	44-64	62.2	4820	0	51.4	0	0	0	0	0	0	0
14-MW03	45-65	62.7	5450	0	190	0.984	0	0	0	0	0	0

Note: Concentrations in micrograms per litre.

^{a/} Distance downgradient from the Site 5/15 source area.

^{b/} Tetrachloroethene.

^{c/} Trichloroethene.

^{d/} cis-1,2-Dichloroethene.

^{e/} 1,1-Dichloroethene.

^{f/} Ethylene dibromide.

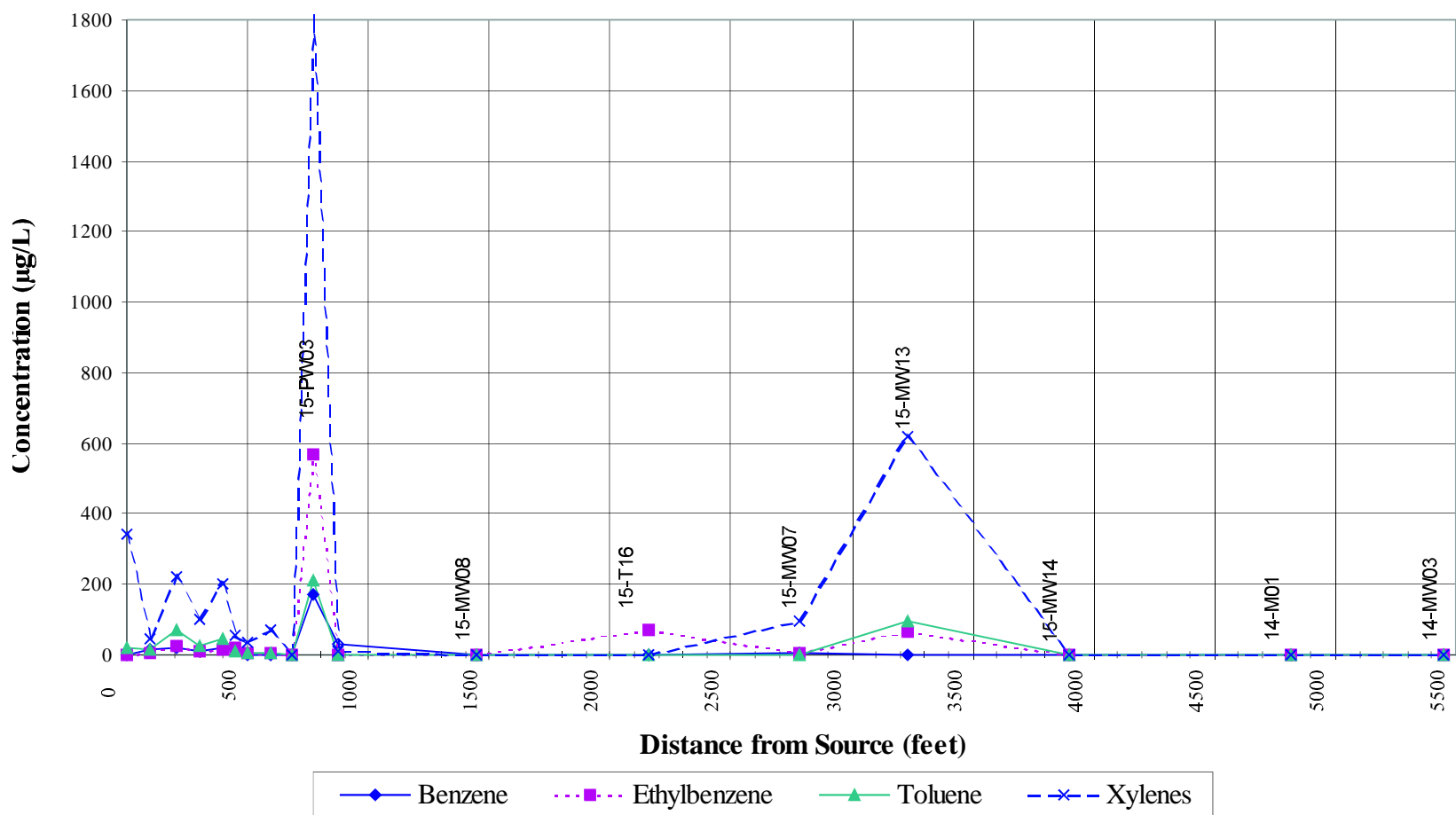


FIGURE 2.2

BTEX CONCENTRATION VERSUS DISTANCE FROM SOURCE

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

Parsons
parsons engineering science, inc.
Denver, Colorado

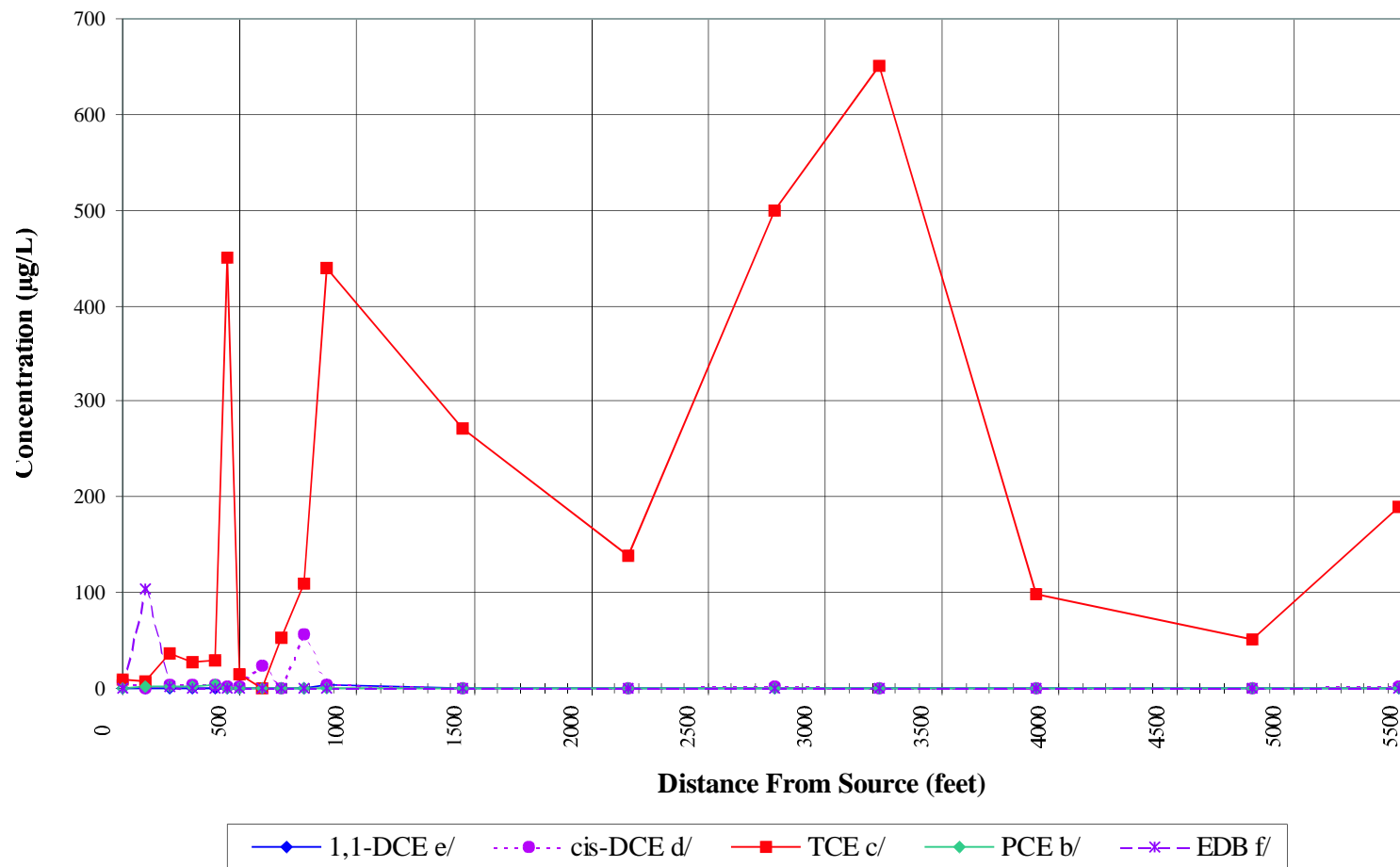


FIGURE 2.3

CHLORINATED VOC CONCENTRATION VERSUS DISTANCE FROM SOURCE

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

Parsons
parsons engineering science, inc.
Denver, Colorado

indicative of reductive dehalogenation, as discussed later in Section 2.3.2. A large increase in TCE concentration also was observed at 3,200 feet downgradient, which is coincident with the BTEX increase at this location. This TCE spike supports the inference of an additional source for the contaminant plume.

2.2.1.2 Concentration Trends Through Time

The second step to evaluate the contaminant plumes at the site was to compare contaminant concentration at selected sampling locations over time. The purpose of this comparison is to assess the evidence of field-scale contaminant mass loss. Decreases in the magnitude of the contaminant concentrations at a site over time that cannot be explained by physical processes (e.g., source removal actions such as SVE and air sparging, or mass transport in groundwater) may be the first indication that contaminants are degrading at the site.

Table 2.2 lists concentrations of COPCs at Site 5/15 sampling locations over several sampling events through time. Graphs of concentrations versus time may be used to interpret if plume concentrations are increasing, decreasing, or are stable at various locations along the plume axis. The rate of change is also important. A slow gradual decline is indicative of first-order decay through dispersion, adsorption, and other physical processes. Second-order decay occurs more rapidly initially, and is indicative of biodegradation. An increase in concentration at a given well at a later time is indicative of source loading or migration of a contaminant slug from an upgradient source.

Figure 2.4 shows concentration versus time graphs for benzene and TCE at locations along the plume axis moving downgradient from the Site 5/15 source area. Generally, benzene concentrations in the aquifer are decreasing, except at 15-PW03. The increase at 15-PW03 could either be the result of remedial system operations, a source-load pulse, or an erroneous data point. The TCE concentration has remained fairly stable at 15-PW03. TCE concentrations have generally decreased or remained stable at each sampling location through time.

2.3 NATURAL ATTENUATION POTENTIAL

Biodegradation of dissolved fuel and solvent constituents and the future migration and persistence of the dissolved COPCs are assessed in this section to support evaluation of the Site 5/15 remedial system and the long term monitoring (LTM) plan. As used here, the term “remediation by natural attenuation” (RNA) refers to a subsurface contaminant remediation strategy that relies on natural physical, chemical, and biological mechanisms to control exposure of potential receptors to concentrations of contaminants that exceed regulatory levels. These mechanisms include the processes of advection, hydrodynamic dispersion, dilution from recharge, sorption, volatilization, and biodegradation, which facilitate RNA of a variety of organic chemicals.

This section summarizes and interprets specific site characterization data relevant to documenting the effectiveness of RNA at minimizing dissolved COPC migration and reducing COPC concentration, mass, and toxicity over time. This assessment was used in the RPO evaluation to determine if natural attenuation may be a useful component in groundwater remediation at the site.

TABLE 2.2
CONTAMINANTS OF POTENTIAL CONCERN IN GROUNDWATER
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Location Identification	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	Total Xylenes (µg/L)	1,2,4-Trimethyl-benzene (µg/L)	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Ethylene Dibromide (µg/L)
5-MW03	10/21/96	16	14	ND	8.2						4
	10/16/97	ND	ND	ND	ND	ND	ND	6.5	ND	ND	ND
	06/16/98	ND	ND	ND	ND	ND	ND	3.1	ND	ND	ND
	10/19/98	ND	ND	ND	ND	ND	ND	1.6	ND	ND	ND
	04/13/99	ND	ND	ND	ND	ND	ND	1.08	ND	ND	ND
5-MW04-deep	10/22/96	ND	ND	ND	ND	ND	ND	6.9	ND	ND	ND
	10/16/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	06/16/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	07/01/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/19/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	04/13/99	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5-MW06	10/31/96	ND	ND	ND	ND	ND	ND	86	ND	ND	1.1
	10/23/97	ND	ND	ND	ND	ND	ND	5.1	ND	ND	0.11
	06/22/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/19/98	ND	ND	ND	ND	ND	ND	5.2	ND	ND	ND
	04/14/99	ND	ND	ND	ND	ND	ND	1.98	ND	ND	ND
5-MW10	10/22/96	ND	15	25	43	34	ND	ND	ND	ND	ND
	10/13/97	ND	1.3	2.3	4.5	4.2	ND	ND	ND	ND	ND
5-MW11	10/23/96	1200	840	130	65	35	ND	1500	ND	ND	180
	03/07/97	1300	2500	120	190	ND	ND	1500	ND	ND	400
5-MW13	06/22/98	ND	5.8	3.2	183	180	1.3	25	ND	ND	ND
	10/19/98	ND	1.8	1	29	55	ND	19	ND	ND	ND
	04/20/99	ND	0.95	ND	58	110	ND	9.5	ND	ND	ND
5-MW14	07/01/98	46	28	44	258	110	ND	540	ND	ND	0.32
	10/26/98	14	2.8	23	81	65	ND	230	ND	ND	0.12
	04/20/99	16	8.2	18	55	50	0.6	450	1.5	0.68	ND
5-MW15	10/28/96	7.8	ND	ND	ND	ND	ND	33	ND	ND	0.056
	10/15/97	ND	ND	ND	ND	ND	ND	12	ND	ND	ND
5-MW16	10/28/96	ND	ND	ND	ND	ND	ND	4.1	ND	ND	ND
	10/15/97	ND	ND	ND	ND	ND	ND	6.4	ND	ND	ND
	06/18/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/26/98	ND	ND	ND	ND	ND	ND	1.3	ND	ND	ND
	04/13/99	ND	ND	ND	ND	ND	ND	0.27	ND	ND	ND
5-MW17	10/16/96	ND	ND	ND	ND	ND	ND	5.9	ND	ND	ND
	10/15/97	ND	ND	ND	ND	ND	ND	3	ND	ND	ND
	06/18/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/26/98		ND	ND	ND	ND	ND	ND	ND	ND	ND
5-MW18-deep	07/29/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	
	06/22/98	ND	ND	4.9	15.8	ND	ND	ND	ND	ND	ND
	10/26/98	ND	ND	4.9	15.8	ND	ND	ND	ND	ND	ND
	04/13/99	ND	ND	ND	0.373	ND	ND	ND	ND	ND	ND
5-OW01	10/24/96	2300	550	230	126	ND	550	1000	ND	ND	9.2
	10/23/97	69	2.8	78	ND	ND	2.8	110	ND	ND	ND
5-PW01	10/24/97	360	1200	250	1850	390	ND	80	ND	ND	2
	06/19/98	2.7	7.6	2.1	43						0.25
	10/23/98	1.8	9	3.8	78	33	ND	2.1	2.8	ND	ND
	04/22/99	ND	20	ND	340	73	ND	8.6	7.6	ND	0.2
5-PW02	04/24/97	36	21	5.6	85	22	1.2	7.3	ND	ND	0.83
	10/24/97	160	390	85	930	370	ND	21	ND	ND	1.6
	06/19/98	14	12	ND	78	ND	2.4	8.7	1.3	ND	0.18
	10/23/98	84	12	11	88	5.7	ND	4.4	1.2	ND	0.17
	04/22/99	16	17	4.1	43	5.6	1.1	6.9	0.75	0.42	103

TABLE 2.2
CONTAMINANTS OF POTENTIAL CONCERN IN GROUNDWATER
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Location Identification	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	Total Xylenes (µg/L)	1,2,4-Trimethyl-benzene (µg/L)	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Ethylene Dibromide (µg/L)
5-PW03	04/24/97	310	1100	250	1560	510	ND	230	ND	ND	3.6
	10/24/97	320	1400	280	1890	450	ND	500	ND	ND	8.2
	06/19/98	1.1	7.7	2.9	24.9	ND	ND	16	ND	ND	0.14
	10/23/98	2.6	9.5	2.2	26.1	17	ND	9.3	3.1	ND	0.09
	04/22/99	19	72	24	219	28	2.3	36	4.4	0.7	0.92
5-PW04	04/24/97	6.8	35	16	237	95	5.3	31	ND	ND	0.1
	10/24/97	22	90	27	183	84	ND	23	ND	ND	7.1
	06/19/98	11	38	18	150	62	1.6	27	1.5	ND	1.2
	10/23/98	1.1	ND	ND	3.5	2.2	ND	14	5.9	ND	ND
	04/22/99	8.9	23	10	102	23	1.3	28	3.1	ND	0.29
5-PW05	04/24/97	ND	ND	ND	1.7	ND	ND	9.5	ND	ND	0.062
	10/24/97	29	60	27	184	99	ND	44	ND	ND	0.58
	06/19/98	34	130	84	420	150	4.8	38	34	ND	0.23
	10/23/98	2.3	17	14	106	63	ND	13	ND	ND	0.06
	04/23/99	21	44	ND	242	36	3.3	29	4.4	ND	0.53
5-PW06	04/24/97	28	47	16	129	ND	ND	41	ND	ND	0.095
	10/24/97	21	170	68	650	ND	ND	78	ND	ND	0.14
	06/19/98	ND	1.8	1.9	14.7	7.4	ND	16	1.1	ND	ND
	10/23/98	1.3	4.5	5.1	40	25	ND	14	5.6	ND	ND
	04/23/99	1.3	3.3	3.5	40	7.6	ND	15	1	ND	ND
15-MW02	04/29/99	33	0.62	5.8	0.4	0.25	ND	ND	ND	ND	ND
15-MW07	09/01/95	89	79	72	780	390	ND	1100	4.3	2	ND
	06/17/98	8.1	2.7	13	189	210	ND	570	1.7	ND	ND
	10/26/98	6.3	ND	13	230	240	ND	480	ND	ND	ND
	04/20/99	4.6	0.5	3.6	95	87	ND	500	1.3	ND	ND
15-MW08	10/29/96	18	ND	ND	ND	ND	ND	230	ND	ND	0.069
	10/21/97	16	ND	ND	ND	ND	ND	280	ND	ND	0.076
	06/17/98	2.2	ND	ND	ND	ND	ND	230	ND	ND	ND
	10/26/98	20	ND	ND	ND	ND	ND	230	ND	ND	ND
	04/13/99	2.04	ND	ND	ND	ND	ND	271	2.78	ND	ND
15-MW09	10/18/96	88	ND	31	151	36	ND	290	ND	ND	ND
	10/21/97	6.1	ND	ND	ND	ND	ND	250	ND	ND	ND
	06/17/98	ND	ND	ND	ND	ND	ND	160	ND	ND	ND
	10/26/98	ND	ND	ND	ND	ND	ND	180	ND	ND	ND
	04/13/99	0.459	ND	ND	ND	ND	ND	343	1.36	0.636	ND
15-MW10	10/24/96	ND	ND	ND	ND	ND	ND	2.3	ND	ND	ND
	10/16/97	ND	ND	ND	ND	ND	ND	1.3	ND	ND	ND
	06/17/98	ND	ND	ND	ND	ND	ND	3	ND	ND	ND
	10/26/98	ND	ND	ND	ND	ND	ND	2.3	ND	ND	ND
	04/15/99	ND	ND	ND	ND	ND	ND	2.74	ND	ND	ND
15-MW11	10/17/96	ND	ND	6.7	ND	ND	ND	340	ND	ND	ND
	10/22/97	ND	ND	5.4	5.7	ND	ND	200	1.2	ND	ND
	06/17/98	ND	ND	1.9	2.3	24	ND	47	ND	ND	ND
	10/26/98	ND	ND	1.1	ND	12	ND	40	ND	ND	ND
	04/20/99	ND	ND	0.29	ND	3.2	ND	45	0.67	ND	ND
15-MW12	10/17/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15-MW13	06/22/98	31	110	64	550	300	ND	860	4.2	2.1	0.35
	10/26/98	15	17	19	121	130	ND	750	3.7	ND	0.3
	04/20/99	ND	94	63	620	ND	ND	650	ND	ND	ND
15-MW14	10/18/96	ND	ND	ND	ND	ND	ND	88	ND	ND	ND
	10/20/97	ND	ND	ND	ND	ND	ND	180	ND	ND	ND
	06/16/98	ND	ND	ND	ND	ND	ND	97	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	68	ND	ND	ND
	04/14/99	ND	ND	ND	ND	ND	ND	97.8	ND	ND	ND

TABLE 2.2
CONTAMINANTS OF POTENTIAL CONCERN IN GROUNDWATER
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Location Identification	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	Total Xylenes (µg/L)	1,2,4-Trimethyl-benzene (µg/L)	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Ethylene Dibromide (µg/L)
15-MW15	08/27/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15-MW16	08/26/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15-MW17	08/26/97	0.51	0.21	ND	0.11	ND	ND	180	ND	0.25	0.31
	06/22/98	12	ND	ND	ND	ND	ND	320	ND	ND	0.18
	10/27/98										ND
15-MW18	08/25/97	ND	ND	ND	ND	ND	ND	300	ND	ND	0.094
	06/16/98	ND	ND	ND	ND	ND	ND	340	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	280	ND	ND	ND
15-PW01	04/24/97	1.6	ND	ND	3.8	ND	ND	30	ND	ND	0.09
	10/24/97	ND	100	24	263	50	ND	61	ND	ND	0.75
	06/19/98	23	140	79	1470	370	2.3	51	ND	ND	0.8
	10/23/98	ND	ND	ND	18.7	9.3	ND	17	ND	ND	ND
	04/23/99	ND	ND	2.9	68	14	ND	ND	24	ND	ND
15-PW02	05/14/97	14	6	ND	9.6	ND	ND	140	ND	ND	0.25
	10/24/97	76	81	46	430	120	ND	100	ND	ND	0.27
	06/19/98	37	16	12	94	38	ND	88	3.4	ND	0.054
	10/23/98	84	12	11	88	34	ND	66	78	ND	ND
	04/23/99	ND	ND	ND	ND	ND	ND	53	ND	ND	ND
15-PW03	04/24/97	ND	ND	ND	2.6	ND	ND	20	ND	ND	0.14
	10/24/97	ND	ND	ND	ND	ND	ND	100	ND	ND	ND
	06/19/98	2	ND	ND	2.3	4.6	ND	91	ND	ND	ND
	10/23/98	10	1.6	2.6	33	22	ND	78	ND	ND	ND
	04/23/99	170	210	570	1810	990	ND	110	56	ND	0.23
15-PW04	04/24/97	ND	ND	ND	ND	ND	ND	44	ND	ND	0.071
	10/24/97	34	2.9	4.5	36.8	4.8	ND	390	ND	ND	0.93
	06/19/98	5	ND	ND	1.8	ND	ND	150	ND	ND	ND
	10/23/98	5.2	ND	ND	1	ND	ND	130	ND	ND	ND
	04/23/99	29	0.35	0.34	9.4	1.6	0.23	440	4.2	3	ND
15-T05	10/30/96	ND	ND	ND	ND	ND	ND	250	ND	ND	ND
	10/23/97	ND	ND	ND	ND	ND	ND	390	ND	ND	ND
	06/18/98	7.8	ND	ND	ND	ND	ND	520	5.7	5.1	ND
	10/20/98	3.8	ND	ND	ND	3.1	ND	400	5	3.4	ND
	04/15/99		0.162				0.419	378	4.5	3.93	
15-T16	09/07/93	43	ND	19	5.9	120	ND	240	ND	ND	ND
	11/10/94	30	ND	53	118	130	ND	320	ND	ND	ND
	04/01/95	30	ND	60	171	50	ND	270	ND	ND	ND
	10/01/95	45	ND	130	156	110	ND	380	ND	ND	ND
	06/17/98	8.4	ND	74	97	190	ND	180	ND	ND	ND
	10/20/98	1.3	1.2	68	25.8	190	ND	120	ND	ND	ND
	04/15/99	ND	ND	71.4	ND	84.4	ND	138	ND	ND	ND
15-T29-deep	10/23/96	ND	ND	ND	ND	ND	ND	2.7	ND	ND	ND
	10/17/97	ND	ND	ND	ND	ND	ND	2.2	ND	ND	ND
	06/17/98	ND	ND	ND	ND	ND	ND	9.2	ND	ND	ND
	10/20/98	ND	ND	ND	ND	ND	ND	37	ND	ND	ND
	04/15/99	ND	ND	ND	ND	ND	ND	12.9	ND	ND	ND
15-T31	10/31/96	7.4	ND	ND	ND	ND	ND	63	ND	ND	ND
	10/20/97	ND	ND	ND	ND	ND	ND	130	ND	ND	ND
	06/24/98	ND	ND	ND	ND	ND	ND	60	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	37	ND	ND	ND
	04/29/99	0.32	ND	ND	ND	ND	ND	29	ND	ND	ND

TABLE 2.2
CONTAMINANTS OF POTENTIAL CONCERN IN GROUNDWATER
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Location Identification	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	Total Xylenes (µg/L)	1,2,4-Trimethyl-benzene (µg/L)	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	1,1-DCE (µg/L)	Ethylene Dibromide (µg/L)
15-T34-deep	10/29/96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/14/97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	06/18/98	ND	ND	ND	2.4	ND	ND	ND	ND	ND	ND
	10/20/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-M01	06/23/98	ND	ND	ND	ND	ND	ND	40	ND	ND	ND
	10/28/98	ND	ND	ND	ND	ND	ND	36	ND	ND	ND
	04/16/99	ND	ND	ND	ND	ND	ND	51.4	ND	ND	ND
14-M02	06/23/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/28/98	ND	ND	ND	ND	ND	ND	57	ND	ND	
14-M03	06/23/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/28/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14-M04	04/20/99	9.2	9.2	5.5	11.2	4.5	1.9	14	3.9	1.9	1
14-MW01	06/23/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	
14-MW03	06/23/98	ND	ND	ND	ND	ND	ND	140	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	160	ND	ND	ND
	04/14/99	ND	ND	ND	ND	ND	ND	190	0.984	ND	ND
14-MW04	12/02/98	ND	ND	ND	ND	ND	ND	480	ND	ND	ND
	04/20/99	0.4	ND	ND	ND	ND	ND	320	1.6	0.47	ND
14-MW05	06/23/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	04/12/99	ND	ND	ND	ND	ND	ND	0.219	ND	ND	ND
14-MW06-deep	06/23/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-MW07	12/02/98	ND	ND	ND	ND	ND	ND	5.9	ND	ND	ND
	04/21/99	ND	ND	ND	ND	ND	ND	5.3	ND	ND	ND
14-MW08	12/02/98	ND	ND	ND	ND	ND	ND	11	ND	ND	ND
	04/21/99	ND	ND	ND	ND	ND	ND	23	ND	ND	ND
14-MW09	12/02/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	04/21/99	2.7	2.1		0.96			0.31			
14-MW10	10/27/98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-T02	06/24/98	ND	ND	ND	ND	ND	ND	1.5	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	1.5	ND	ND	ND
14-T04	06/24/98	ND	ND	ND	ND	ND	ND	9.3	ND	ND	ND
	10/27/98	ND	ND	ND	ND	ND	ND	9.5	ND	ND	ND
	04/12/99	ND	ND	ND	ND	ND	ND	11.5	ND	ND	ND

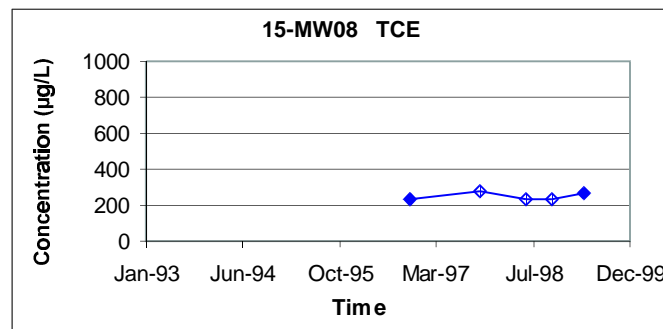
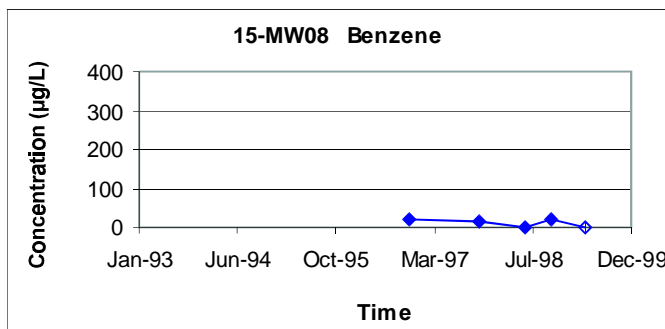
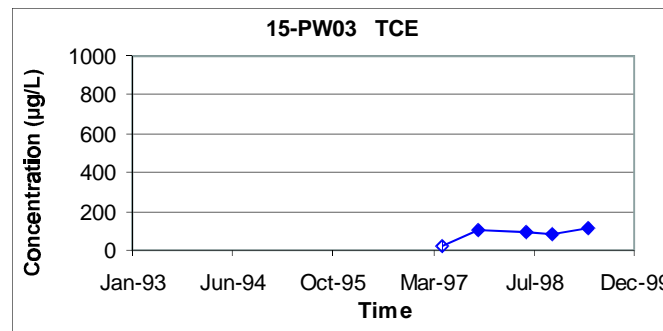
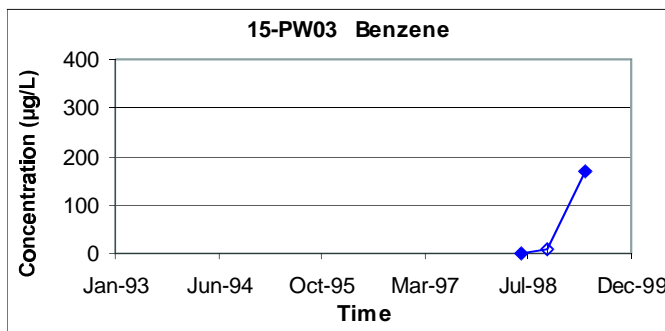
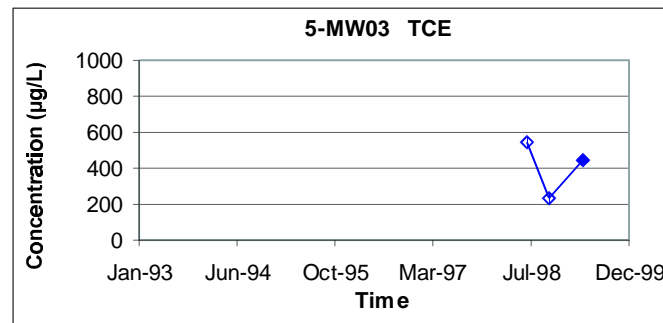
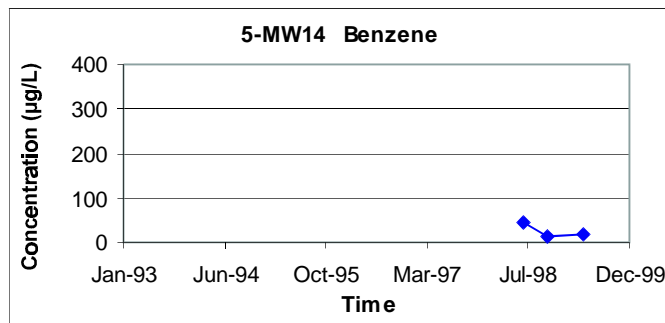
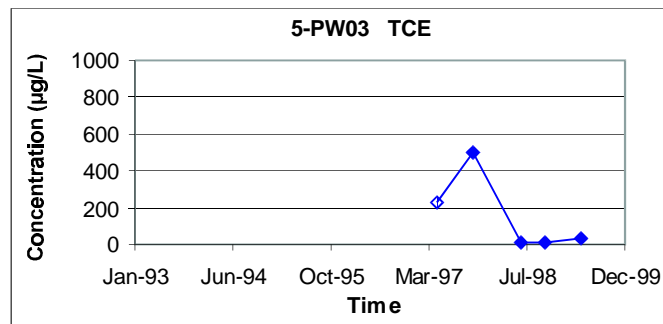
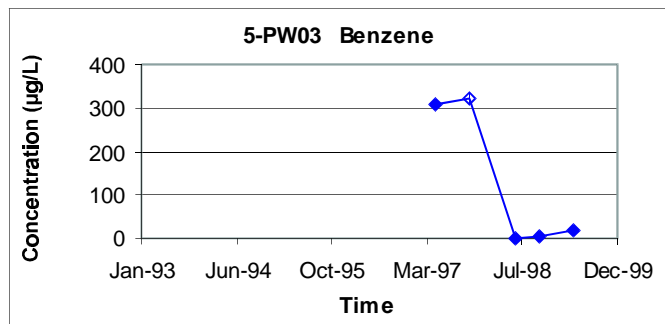


FIGURE 2.4
CONCENTRATION VERSUS
TIME GRAPHS
FOR BENZENE AND TCE

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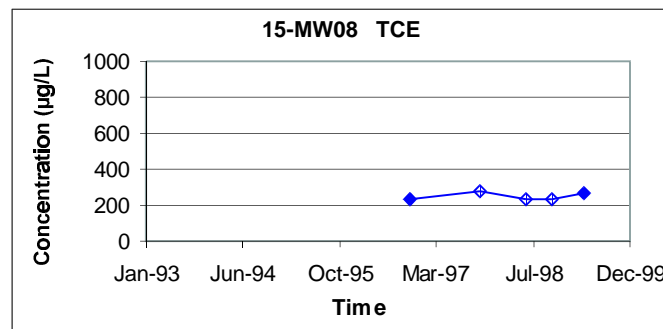
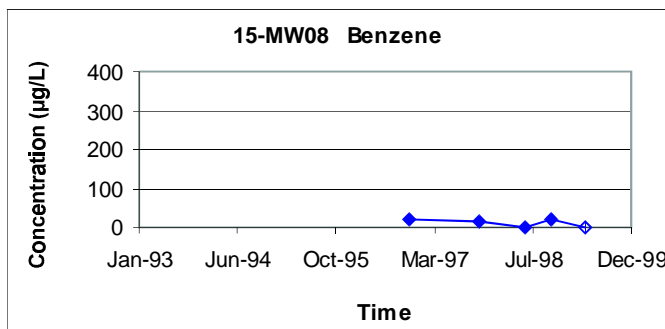
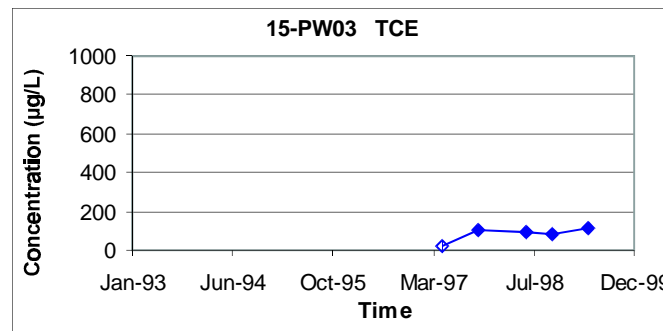
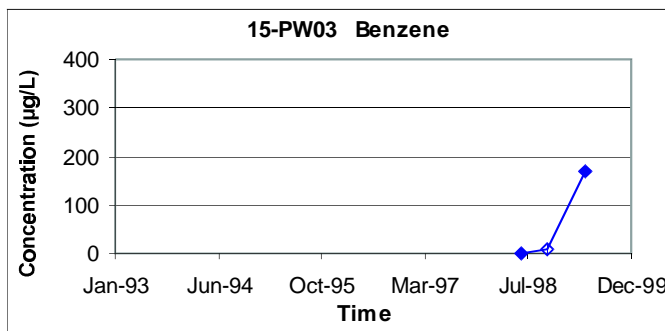
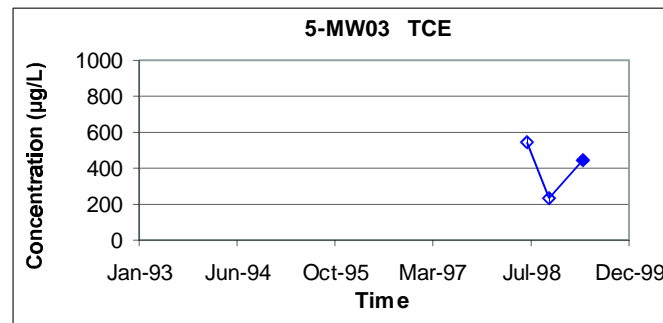
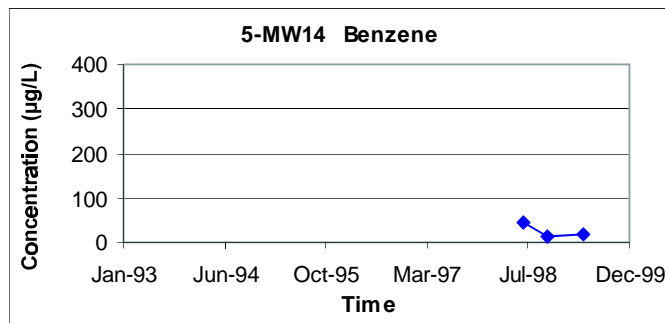
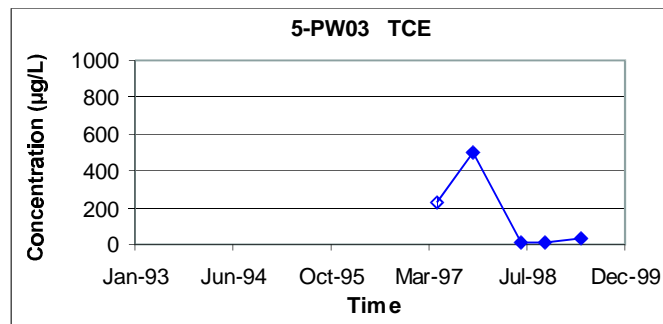
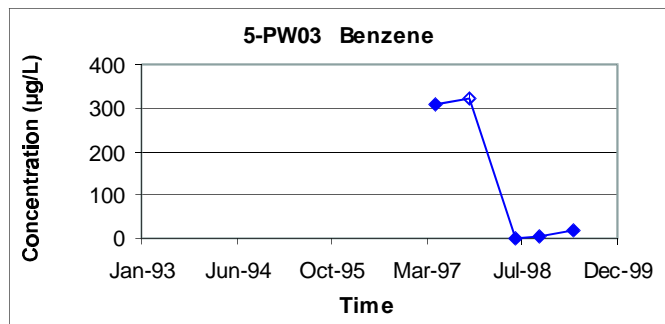


FIGURE 2.4
CONCENTRATION VERSUS
TIME GRAPHS
FOR BENZENE AND TCE

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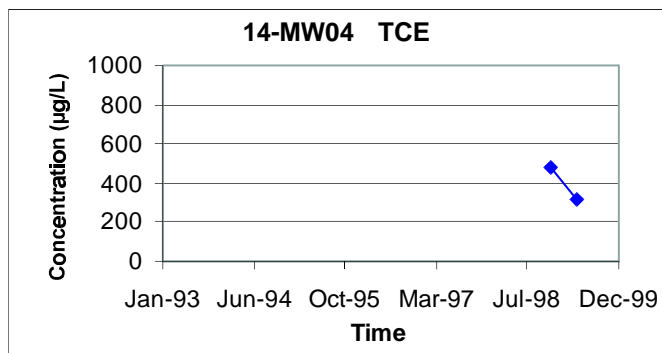
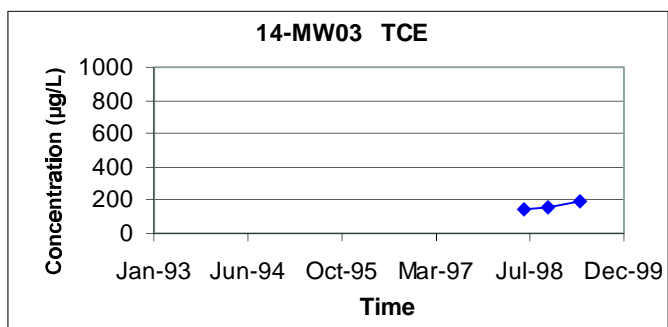
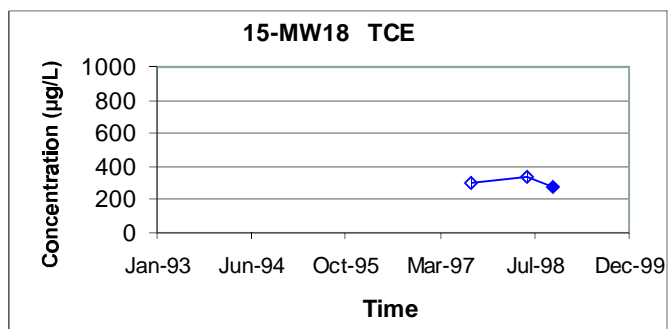


FIGURE 2.4 (continued)
CONCENTRATION VERSUS
TIME GRAPHS
FOR BENZENE AND TCE

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2.3.1 Evidence of Fuel Hydrocarbon Biodegradation Via Microbially Mediated Redox Reactions

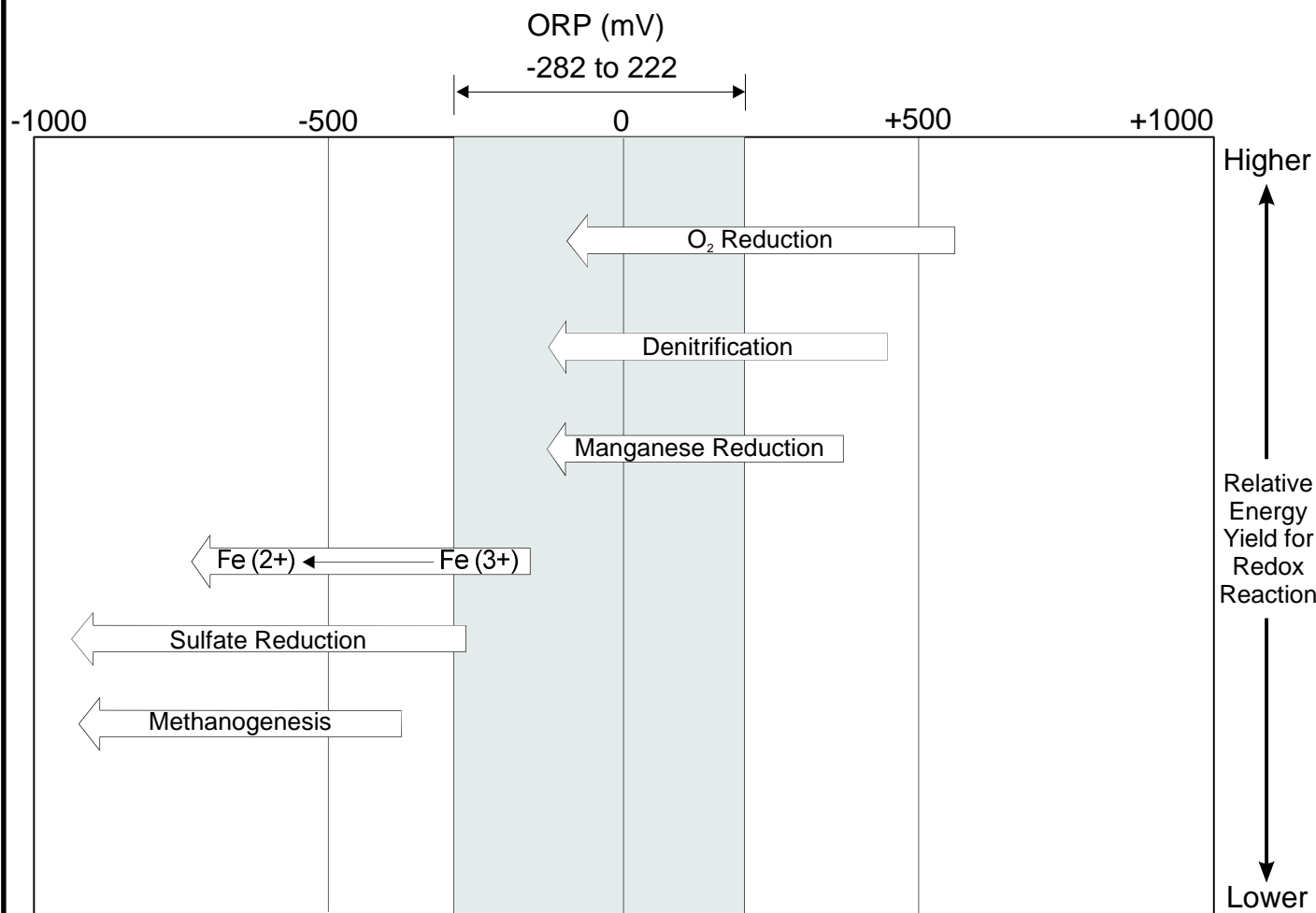
Fuel hydrocarbons are typically utilized as electron donors in biologically mediated redox reactions under a wide range of geochemical conditions. Therefore, analytical data on potential electron acceptors can be used as geochemical indicators of fuel hydrocarbon biodegradation (AFCEE, 1995). Reductions in the concentrations of oxidized chemical species that are used by microorganisms to facilitate the oxidation of fuel hydrocarbon compounds within contaminated media are an indication that contaminants are biodegrading. Alternately, an increase in the metabolic byproducts resulting from the reduction of electron acceptors can be used as an indicator of contaminant biodegradation. The availability of potential electron acceptors to participate in contaminant biodegradation reactions can be used to estimate the total contaminant mass that can be biodegraded over time at this site. This information can be used to predict how much dissolved COPC mass can be removed from saturated soil and groundwater at the site as a result of natural processes.

2.3.1.1 Relevance of Redox Couples in Biodegradation

Microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of dissolved fuel hydrocarbons is the result of a series of redox reactions that maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of these organic compounds by transferring electrons from the electron donor (i.e., fuel hydrocarbons and native organic carbon) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and that can participate in redox reactions involving these available electron donors. Electron acceptors known to be present in saturated soil and groundwater at the site include dissolved oxygen (DO), sulfate (SO_4), ferric iron (Fe^{3+}), and carbon dioxide.

Microorganisms facilitate fuel hydrocarbon biodegradation to produce energy for their use. The amount of energy that can be released when a reaction occurs or that is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981). Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes (i.e., cell production and maintenance). Microorganisms will facilitate only those redox reactions that will yield energy. By coupling the oxidation of fuel hydrocarbon compounds, which requires energy, to the reduction of other compounds (e.g., oxygen, manganese, ferric iron, sulfate, and carbon dioxide), which yields energy, the overall reaction will yield energy.

Figure 2.5 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981). As Figure 2.5 shows, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy. However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate/nitrite, manganese, ferric iron, sulfate, and finally carbon dioxide. Each



Notes

ORP = Oxidation Reduction Potential

Range of ORP measured at Site 5/15

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.
2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the ORP of the system.
3. The ORP of the system determines which electron acceptors are available for organic carbon oxidation.
4. Redox sequence is paralleled by an ecological succession of biological mediators.

FIGURE 2.2

SEQUENCE OF MICROBIALY MEDIATED REDOX PROCESSES

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successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

Microorganisms can facilitate the biodegradation (oxidation) of the fuel hydrocarbon compounds only by using redox couples that have a higher oxidation reduction potential (ORP) than the contaminants. This is why these electron acceptors can be used to oxidize the fuel hydrocarbon compounds. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 2.5, the reduction of oxygen and nitrate will reduce the oxidizing potential to levels at which ferric iron reduction can occur. As each chemical species that can be used to oxidize the contaminants is exhausted, the microorganisms are forced to use other available electron acceptors with lower oxidizing capacity. When sufficiently low (negative) ORP levels have been developed as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

ORP values measured in groundwater at the site in May 1999 ranged from -282 millivolts (mV) to 222 mV (Table 2.3). The two lowest ORP values were measured at wells 5-MW14 and 15-T16, both of which are screened in the dissolved BTEX plume. Conversely, the ORP values measured at upgradient wells 5-MW05 and 5-MW12 were substantially higher, indicating the presence of more oxidizing conditions. The magnitudes of these values indicate that the progressive use of electron acceptors in the order shown on Figure 2.5 has caused the groundwater in the contaminated areas to become more reducing. However, the groundwater may not be sufficiently reducing in all areas to support significant sulfate reduction and methanogenesis.

Many authors have noted that field ORP data alone cannot be used to reliably predict the electron acceptors that may be operating at a site, because the platinum electrode probes are not sensitive to some redox couples (e.g., sulfate/sulfide) (Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994). Dissolved hydrogen concentrations also can be used to determine the dominant terminal electron-accepting process in an aquifer. This method has been shown to provide a direct, independent measurement that identifies which redox reactions are taking place in anaerobic groundwater (Table 2.4) (Lovley and Goodwin, 1988; Lovley *et al.*, 1994; Vroblesky and Chapelle, 1994; Chapelle *et al.*, 1995).

Comparison of the dissolved hydrogen data in Table 2.3 to the information in Table 2.4 indicates that available oxygen, nitrate, and iron may be depleted. Sulfate may be the most available electron acceptor in site groundwater (except at Well 15-T16, where methanogenesis may dominate).

Analytical data on oxidized and reduced species are discussed in the following paragraphs to verify which electron acceptors actually are being used to biodegrade fuel hydrocarbons in saturated soil and groundwater at the site. The distributions of geochemical parameters are examined by comparing background concentrations to BTEX plume core concentrations. Analytical data from upgradient wells 5-MW05 and 5-MW12 are used for background concentrations. Analytical data from wells 5-MW14, 15-T16, and 15-MW07 are used for BTEX plume core concentrations. The dissolved BTEX concentrations detected in these plume wells ranged from 71 µg/L to 104 µg/L. Higher

TABLE 2.3
GROUNDWATER GEOCHEMICAL DATA
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

LOCID ^{a/}	Date Sampled	Water Temp (°C) ^{b/}	pH (su) ^{c/}	Conductivity (mS/cm) ^{d/}	Redox Potential (mV) ^{e/}	Dissolved Oxygen (mg/L) ^{f/}	Nitrate (mg/L as N) ^{g/}	Ammonia (mg/L as N)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)
5-MW05	05/27/99	28.30	7.74	0.743	60.3	4.98	<20	0.028	0.00	0.1	86.9
5-MW12	05/27/99	27.40	7.62	0.676	113.3	6.29	<10	0.028	0.10	0.3	80.2
5-MW04	05/28/99	20.70	7.79	0.746	-35.1	0.35	<5	0.006	0.00	0.5	99.7
5-MW04 (FD) ^{h/}	05/28/99						<5				101
5-MW06	05/27/99	21.50	7.98	0.696	107.1	3.11	<13	0.007	0.00	0.0	83
5-MW14	05/25/99	22.34	7.65	0.738	-111.5	5.86 ^{i/}	<25	0.046	0.22	0.5	57.8
15-MW08	05/26/99	22.26	7.37	3.668	15.7	3.68	<200	0.051	0.84	3.7	525
15-MW08 (FD) ^{h/}	05/26/99						<200				503
15-T16	05/26/99	22.40	7.40	4.496	-281.8	0.00	<130	0.134	0.60	3.8	1450
15-MW07	05/26/99	22.05	7.78	1.659	49.1	1.89	<100	0.000	0.24	0.0	92.9
15-MW11	05/25/99	22.30	7.34	1.701	74.7	0.41	<80	0.880	0.02	0.3	365
15-MW14	05/25/99	20.85	8.01	1.692	222.0	1.80	<130	0.040	0.33	0.0	69.6
14-MW03	05/26/99	20.82	8.00	1.568	141.2	0.58	<100	0.008	0.11	0.0	131

a/ LOCID = Location Identification.

b/ °C = degrees Celsius.

c/ su = Standard pH units.

d/ mS/cm = microsiemens per centimeter.

e/ mV = millivolts.

f/ mg/L = milligrams per liter.

g/ milligrams per liter as total nitrogen.

h/ FD = Field Duplicate.

i/ Equipment problems caused air bubbles to occur in the flow-through cell during sampling.

TABLE 2.3 (Continued)
GROUNDWATER GEOCHEMICAL DATA
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

LOCID ^{a/}	Methane (mg/L)	Ethylene (mg/L)	Ethane (mg/L)	Carbon Dioxide (mg/L)	Total Alkalinity (mg/L)	Chloride (mg/L)	Hydrogen (mg/L)	Dissolved Organic Carbon
								Carbon (mg/L)
5-MW05	<3	<3	<3	<10	140	99.3		<1
5-MW12	<3	<3	<3	<10	220	45.6		2.7
5-MW04	<3	<3	<3	<10	240	30.3	1.15	3.8
5-MW04 (FD1)	<3	<3	<3			31.2	1.42	<1
5-MW06	<3	<3	<3	<10	180	67.4	1.46	2
5-MW14	<3	<3	<3	14	300	122		1.5
15-MW08	<3	<3	<3	18	260	1110	1	2.8
15-MW08 (FD1)	<3	<3	<3			1080	0.98	1.3
15-T16	28.5	<3	<3	54		493	8.2	25.4
15-MW07	<3	<3	<3	<10	140	513	1.38	4.3
15-MW11	<3	<3	<3	35	320	353		<1
15-MW14	<3	<3	<3	<10	120	601		1.5
14-MW03	<3	<3	<3	<10	120	460	1.42	<1

a/ LOCID = Location Identification

b/ °C = degrees Celsius.

c/ su = Standard pH units.

d/ mS/cm = microsiemens per centimeter.

e/ mV = millivolts.

f/ mg/L = milligrams per liter.

g/ milligrams per liter as total nitrogen.

h/ FD = Field Duplicate.

i/ Equipment problems caused air bubbles to occur in the flow-through cell during sampling.

TABLE 2.4
RANGE OF HYDROGEN CONCENTRATIONS FOR GIVEN
TERMINAL ELECTRON-ACCEPTING PROCESSES
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
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Terminal Electron-Accepting Process	Hydrogen Concentration (nanomoles per liter)
Denitrification	<0.1
Iron (III) Reduction	0.2 to 0.8
Sulfate Reduction	1 to 4
Methanogenesis	>5

Source: Chapelle *et al.*, 1995.

BTEX concentrations were detected in groundwater samples from some of the pumping wells; however, geochemical data for these wells are not available.

2.3.1.2 Electron Acceptors

As described above, concentrations of electron acceptors are generally diminished within the core of dissolved fuel hydrocarbon plumes. DO values measured in site groundwater ranged from 0.0 to 6.3 mg/L, with the lowest and highest values detected within and upgradient from the BTEX plume, respectively (Table 2.3). This disparity between plume and background DO concentrations strongly supports the occurrence of aerobic biodegradation of BTEX in the vicinity of well 15-T16. The detection of 5.86 mg/L of DO at 5-MW14 is anomalous given the relatively low ORP and the presence of ferrous iron and manganese (both of which are metabolic byproducts of the anaerobic biodegradation of organic carbon). This anomalous measurement is likely due to equipment problems that caused air bubbles to occur in the flow-through cell during sample analysis. However, the presence of detectable DO concentrations within the dissolved BTEX plume suggests that fuel hydrocarbon concentrations are not sufficiently elevated in some areas to promote significant microbial activity. It is also feasible that operation of the groundwater extraction wells at the site draws oxygenated groundwater into the plume area, and that dissolved fuel hydrocarbon concentrations are not sufficiently elevated in some areas to quickly deplete the DO.

Nitrate was not detected in any of the May 1999 groundwater samples, indicating that denitrification and nitrate reduction are not significant fuel hydrocarbon biodegradation processes in site groundwater. However, some of the reporting limits for nitrate were elevated (up to 200 mg/L); therefore, nitrate concentrations were not precisely quantified in all samples. The average background and BTEX plume core sulfate concentrations were 84 mg/L and 538 mg/L, respectively based on data from the five wells listed above. The sulfate concentration was particularly elevated in the sample from 15-T16 (1,450 mg/L). Based on the dissolved hydrogen results, sulfate reduction may be occurring at

least locally in site groundwater. However, if this process is occurring in the BTEX plume, it is masked by the high sulfate concentrations present in the groundwater.

2.3.1.3 Metabolic Byproducts

The geochemical data indicate that ferrous iron and (locally) soluble manganese are being produced in the plume area as a result of ferric iron and manganese reduction (Table 2.3). The arithmetic mean plume core ferrous iron and manganese concentrations in May 1999 were 0.39 mg/L and 0.46 mg/L, respectively, compared to background concentrations of 0.05 mg/L and 0.2 mg/L, respectively. Methane production appears to be extremely localized to the vicinity of well 15-T16 (consistent with the dissolved hydrogen result for this well), indicating that in general, the groundwater in the plume area is not sufficiently reducing to support the occurrence of methanogenesis.

The presence of ammonia in groundwater can result from either nitrate reduction (facilitated by microbes), fixing of atmospheric nitrogen (also a microbial process), or anthropogenic sources such as land application of fertilizer. If the presence of ammonia in groundwater results from nitrate reduction or fixing of atmospheric nitrogen, it is a strong indication of microbial activity. The ammonia concentrations in plume wells 5-M14 and 15-T16 were higher than background concentrations of this constituent. However, the average plume core ammonia concentration (0.06 mg/L) was similar to the average background concentration (0.028 mg/L), suggesting that microbially-mediated ammonia production is not a significant process at this site. This observation is consistent with the lack of detectable nitrate concentrations in site groundwater.

2.3.1.4 Alkalinity

In aquifers that have carbonate minerals as part of the matrix, carbon dioxide forms carbonic acid, which dissolves these minerals, increasing the alkalinity of the groundwater. An increase in alkalinity [measured as calcium carbonate (CaCO_3)] in an area with BTEX concentrations elevated above background conditions can be used to infer that petroleum hydrocarbons (or native organic carbon) have been destroyed through aerobic and anaerobic microbial respiration.

Total alkalinity (as CaCO_3) was measured in groundwater samples collected in May 1999 (Table 2.3). Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site varied from 120 mg/L to 320 mg/L. This range of alkalinity is likely sufficient to buffer potential changes in pH caused by biologically mediated reactions and suggests that aerobic and/or anaerobic biodegradation processes should not cause detrimental shifts in groundwater pH. The neutral to slightly basic pH values measured in site groundwater support this observation. The alkalinities measured in the plume area average 210 mg/L, indicating a slight alkalinity enrichment above the background concentration of 180 mg/L, due to biodegradation. The similarity of these values suggests either that dissolved BTEX concentrations are too low to promote significant carbonic acid formation or that the carbonate content of the aquifer is low.

2.3.1.5 BTEX Assimilative Capacity of Site Groundwater

The coupled redox reactions that represent the biodegradation of the BTEX compounds, including the stoichiometric mass ratio of electron acceptors needed to oxidize each compound, can be used to estimate the assimilative capacity of the groundwater at Site 5/15. For oxygen, nitrate, and sulfate, this is accomplished by first determining the initial (background) mass of each electron acceptor available in the groundwater. Data on these chemical species were collected at sampling locations upgradient and cross-gradient from the dissolved plume. As groundwater slowly migrates into the source area, electron acceptors are brought into contact with hydrocarbon-degrading microorganisms and site contamination. The change in the electron acceptor mass from background sampling locations to sampling locations within the plume core is divided by the mass of electron acceptors required to mineralize the contaminants. For ferrous iron and methane, the average concentration in the plume core wells is divided by the mass of electron acceptors required to mineralize the COPC. These numbers are summed to estimate the expressed intrinsic capacity of the groundwater to biodegrade each COPC.

Estimates of the background and plume core concentrations were used to calculate the assimilative capacity of the groundwater system attributable to aerobic respiration, ferric iron and manganese reduction, and methanogenesis. Nitrate was not included because it was not detected in site groundwater, and sulfate was not included because the average plume core sulfate concentration was higher than the background concentration of this analyte. The source area concentrations of ferrous iron and methane are used to “back-calculate” the mass reduction capacity that is attributable to ferric iron reduction and methanogenesis. The calculation results are summarized in Table 2.5. This estimate essentially represents an estimate of the assimilative capacity of one pore volume of groundwater at the site. The estimate identifies how much contaminant mass can be theoretically oxidized as one pore volume travels through the plume core.

On the basis of these calculations, one pore volume of saturated soil and groundwater at Site 5/15 has the capacity to oxidize an average total BTEX concentration of approximately 13,000 µg/L. The maximum total BTEX concentration detected in site groundwater in May 1999 was 2,760 µg/L. With this excessive assimilative capacity, one would expect the BTEX plume to be much shorter. However, the long length of the BTEX plume is determined by the length and persistence of the LNAPL (free product) plume which acts as a continuing source of contamination.

As an example to help visualize the physical meaning of assimilative capacity, consider a closed system containing 2 liters of water. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has an assimilative capacity of exactly “x” mg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these 2 liters of water are kept separate, biodegradation of fuel hydrocarbons will not occur. If these 2 liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons or electron acceptors are depleted. If less than “x” mg of fuel hydrocarbons are in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than “x” mg of fuel hydrocarbons were in the second liter of water, only “x” mg of fuel hydrocarbons would ultimately degrade.

TABLE 2.5
ESTIMATED ASSIMILATIVE CAPACITY OF SATURATED SOIL AND GROUNDWATER
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Electron Acceptor or Metabolic Byproduct	Background Concentration ^{a/} (mg/L) ^{b/}	Concentration in Fuel Hydrocarbon Plume ^{c/} (mg/L)	Mass Ratio of Electron Acceptor/ Byproduct to Contaminants ^{d/} (unitless)	BTEX Assimilative Capacity ^{e/} (mg/L)
Oxygen	5.64	1.23	3.14	1.4
Ferrous Iron	0.05	0.39	21.8	0.02
Methane	1.5	10.5	0.78	11.5
Manganese	0.2	1.27	11.0	0.1
Total				13.0
Max. 1999 Concentration (BTEX) (mg/L)				2.76

^{a/} Background concentrations were averaged from two background wells (5-MW05 and 5-MW12).

^{b/} mg/L = milligrams per liter.

^{c/} Concentrations in the plume were averaged from three plume wells (15-MW14, 15-MW07, and 15-T16).

^{d/} Calculation based on the ratio of the total mass of electron acceptor required to oxidize a given mass of contaminant.

^{e/} Assimilative capacity is the amount of contaminant that can be degraded by a given process.

This example shows that in a closed system, the measured expressed assimilative capacity eventually should be equivalent to the loss in contaminant mass; however, the groundwater beneath the site is an open system. Electron acceptors can continually enter the system from upgradient flow. Furthermore, contaminant mass can be added to the system through dissolution or leaching from LNAPL or contaminated soil. This means that the assimilative capacity is not fixed as it would be in a closed system, and therefore should not be quantitatively compared to concentrations of dissolved contaminants in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. The fate of BTEX in groundwater is dependent on the relationship between the kinetics of biodegradation and the solute transport velocities (Chapelle, 1994).

2.3.1.6 Observed BTEX Plume Migration

The geochemical data presented above indicate that dissolved fuel hydrocarbons are being biodegraded. This conclusion is strongly supported by the fact that the dissolved BTEX plume has not migrated a substantial distance beyond the free product plume, which is a continuing source of BTEX to the groundwater. In contrast, the TCE plume has migrated a relatively long distance. Both TCE and the BTEX compounds are typically relatively soluble and mobile in the environment (i.e., their migration does not tend to be extremely retarded relative to the advective groundwater flow velocity due to sorption to aquifer matrix materials). Comparison of these two plumes indicates that biodegradation is significantly limiting the downgradient migration of dissolved BTEX.

2.3.2 Evidence of CAH Biodegradation Via Microbially Mediated Redox Reactions

Chlorinated aliphatic hydrocarbons (CAHs) can be transformed, directly or indirectly, by biological processes. Biodegradation of CAHs is similar in principle to biodegradation of BTEX as described in Section 2.3.1.1; however, CAH degradation typically results from a more complex series of processes.

Whereas BTEX is biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs may undergo biodegradation through these three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated microbial process. A fourth degradation mechanism that may occur is abiotic degradation, including hydrolysis and dehydrohalogenation reactions. However, attributing degradation of CAHs to abiotic processes is usually difficult, particularly at the field scale (Butler and Barker, 1996).

At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most likely. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.3.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen

atom is removed and replaced with a hydrogen atom. In general, reductive dehalogenation of chlorinated ethenes occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. The rate of reductive dehalogenation has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in TCE plumes that are undergoing reductive dehalogenation.

In addition to being affected by the degree of chlorination of the CAH, reductive dehalogenation can also be controlled by the ORP conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or ferric iron reduction (Vogel *et al.*, 1987), while the transformation of DCE to VC, or the transformation from VC to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; DeBruin *et al.*, 1992).

Because CAHs are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons such as BTEX, or added carbon sources such as vegetable oil.

2.3.2.2 Electron Donor Reactions

Under aerobic conditions some CAHs can be utilized as the primary substrate (i.e., electron donor) in biologically mediated ORP reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the less oxidized CAHs can be utilized as electron donors in biologically mediated ORP reactions.

Davis and Carpenter (1990) and McCarty and Semprini (1994) describe the aerobic oxidation of VC in groundwater. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Klier *et al.* (1996) write that naturally occurring microorganisms in soil and groundwater are capable of biodegrading DCE by using this compound as a

primary substrate (i.e. an electron donor). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic oxidation of VC and DCE or reduction of VC under iron-reducing conditions may be characterized by contaminant mass loss, a decreasing molar ratio of DCE and/or VC to other CAH compounds, and the presence of elevated carbon dioxide concentrations.

2.3.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated ORP reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather, the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases.

2.3.2.4 Summary of CAH Biodegradation at Site 5/15

The prevalence of TCE throughout the CAH plume, combined with the relative absence of reductive dehalogenation daughter products (i.e., *cis*-1,2-DCE, VC, and ethene), is a direct indication that significant biotransformation of TCE via reductive dehalogenation is not occurring despite the localized presence of anaerobic, reducing conditions in site groundwater. This conclusion is supported by the following observations:

- Although fuel contamination has created anaerobic conditions in areas of high dissolved BTEX, groundwater is not sufficiently reducing throughout the TCE plume area to promote significant reductive dehalogenation. This is evidenced by the lack of consistently anaerobic conditions, the low magnitude of the ferrous iron concentrations (less than 1 mg/L), the paucity of detected methane concentrations (except at well 15-T16), and the overall low magnitude of dissolved organic carbon concentrations (except at well 15-T16). According to the USEPA (1998), dissolved organic carbon concentrations less than 20 mg/L may not constitute a sufficient carbon and energy source to drive reductive dehalogenation.
- According to the USEPA (1998), sulfate may compete with CAHs as an electron acceptor (i.e., sulfate may be preferentially used by microorganisms instead of CAHs) if sulfate concentrations exceed 20 mg/L. As described in Section 2.3.1.2, the average sulfate concentration in three BTEX plume core wells was 538 mg/L, and the average sulfate concentration in site groundwater considering data for all 13 sampled wells was 280 mg/L. Therefore, although available data indicate that redox conditions appear to be suitable for reductive dehalogenation to occur on a localized

basis, it appears that sulfate is being preferentially used as an electron acceptor in site groundwater, limiting biotransformation of TCE.

As discussed in Section 2.3.2.2, highly chlorinated CAHs such as TCE cannot be aerobically biodegraded. Therefore, significant biodegradation of TCE in more aerobic and oxidizing regions of the site outside of the dissolved fuel hydrocarbon plume is not feasible. Less-chlorinated CAHs such as cis-1,2-DCE and VC are typically more easily biodegraded in aerobic environments. However, production of these compounds appears to be extremely limited at this site. Cometabolic or abiotic transformation of TCE may be occurring in site groundwater. However, occurrence of these processes is difficult to document. Because the cometabolism rate decreases with increasing degree of chlorination, it is likely that cometabolism of TCE, if it is occurring in site groundwater, is occurring at a slow rate.

Chlorine is removed from CAHs during reductive dehalogenation and enters solution. Therefore, chloride concentrations in groundwater should increase above background levels in areas where reductive dehalogenation is taking place. May 1999 chloride concentrations are presented in Table 2.3, and plotted against dissolved CAH and BTEX concentrations on Figure 2.6. Chloride concentrations at and upgradient from the head of the contaminant plume are relatively low compared to concentrations further downgradient in the CAH plume. This information, taken by itself, suggests that reductive dehalogenation of TCE is occurring. However, the lack of reductive dehalogenation daughter products indicates that the chloride measured in the plume area does not result from the occurrence of this process, but may be indicative of natural variation in the aquifer. This observation is supported by the fact that the chloride concentration at well 15-T16, where the most anaerobic, reducing conditions (conducive to reductive dehalogenation) were encountered, was not higher than chloride concentrations detected along the TCE plume axis further upgradient and downgradient.

2.4 RISK EXPOSURE PATHWAYS AND RECEPTORS

Receptors that may potentially be impacted by the Site 5/15 contaminants include industrial workers who may excavate contaminated soils. The exposure pathways for industrial workers are ingestion of, or dermal contact with, contaminated soil; or through inhalation of vapors or particulates/fugitive dust. Groundwater, at 50 feet bgs, does not present a concern for the industrial worker.

Under future land use conditions, groundwater potentially may be used as a drinking water source. There currently are no production wells within the limits of the plume. The nearest production wells are located at the sled track area approximately 2.5 miles south of Site 14, not along the groundwater flow path. The pump and treat system at Site 14 appears to be effective in limiting expansion of the plume downgradient of the system. Administrative controls could be utilized to prevent future use of groundwater in the area of the plume as a drinking water source on the base.

2.5 UPDATE OF CSM BASED ON REMEDIAL SYSTEM OPERATIONS

The only revision to the conceptual model, based on system performance and monitoring data, is the interpretation of possible multiple contaminant source areas.

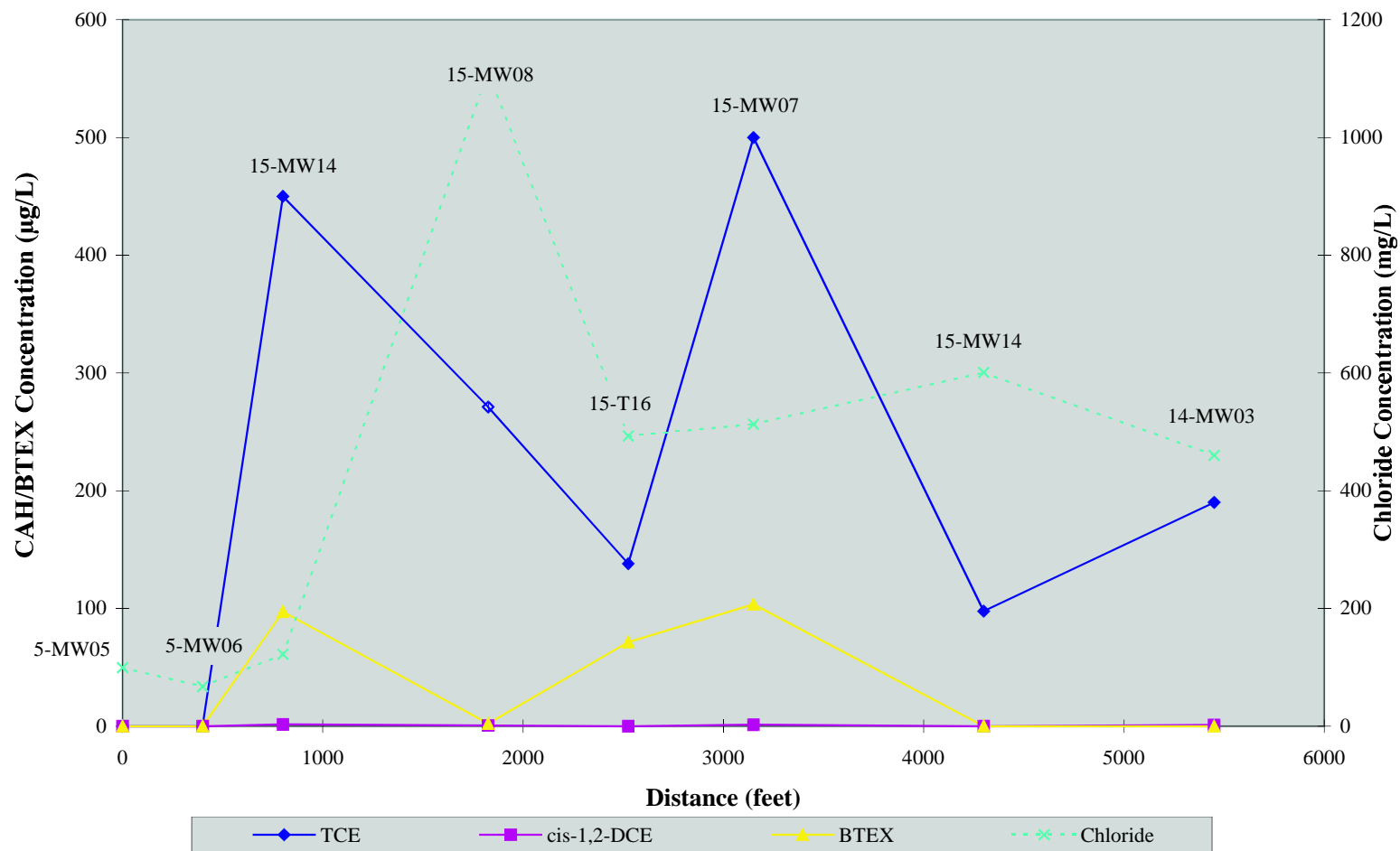


FIGURE 2.6

CONCENTRATION VERSUS DISTANCE FROM WELL 5-MW05

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

Parsons
parsons engineering science, inc.
Denver, Colorado

Figures 2.5 and 2.6 clearly indicate the likelihood of a second source area slightly upgradient from monitoring well 15-MW07. This modification is depicted on the CSM (Figure 2.1) and does not impact the remediation strategy. The evaluation of intrinsic remediation data has indicated that the hydrocarbon plume is naturally attenuating, but natural attenuation processes only minimally impact the TCE plume.

SECTION 3

EVALUATION OF CLEANUP GOALS

This RPO evaluation provides an opportunity to review the cleanup goals for Site 5/15, and to promote additional interaction and communication with regulatory officials responsible for oversight of remediation activities. Updated site information can potentially lead to revision of cleanup goals. A ROD has not been prepared, and formal cleanup goals have not been established for Site 5/15. The purpose of this section is to evaluate the preliminary cleanup goals proposed in the EE/CA (Earth Tech 1996a) and provide recommendations on potential cleanup goals given the current regulatory framework and the performance of the operating remedial system.

3.1 REVIEW OF DECISION DOCUMENT AND CLEANUP OBJECTIVES

IRAs were implemented based on the decisions documented in the Action Memorandum for Site 5/15 (Earth Tech, 1997a) to address hydrocarbon-contaminated soil and groundwater at the Site 5/15. IRAs were implemented to address the contaminant plume because:

- Contaminants in the soil and groundwater could pose a threat to human health via contact and ingestion; and
- There is potential for further degradation of groundwater underlying the site.

The National Contingency Plan (NCP) allows for the lead agency, the Air Force, to determine if conditions that may pose a threat to public health, welfare, or to the environment exist on Air Force property. The NCP specifies eight criteria, cited in Title 40 of the Code of Federal Regulations (CFR) Section 300.415, that should be considered in making this determination. The following provisions of §300.415 were used to justify the IRA at Site 5/15 (Earth Tech, 1996f):

- §300.415(b)(2)(I) “Actual or potential exposure to nearby human population, animals, or the food chain from hazardous substances or pollutants or contaminants;”
- §300.415(b)(2)(ii) “Actual or potential contamination of drinking water supplies or sensitive ecosystems;” and
- §300.415(b)(2)(iv) “High levels of hazardous substances or pollutants or contaminants in soil largely at or near the surface that may migrate.”

3.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Applicable or relevant and appropriate requirements (ARARs) are divided into three categories: chemical-specific, action-specific, and location-specific. Chemical-specific ARARs establish numerical standards limiting the concentration of substances in the medium of concern and/or the medium affected by the removal action. Action-specific ARARs are technology- or activity-based restrictions controlling the removal action, and include performance and design standards. Location-specific ARARs are restrictions or considerations placed upon the conduct of activities because they are in special locations (e.g., sensitive habitat). Potential ARARs identified for the IRA are provided in Appendix C of the EE/CA prepared for Site 5/15 contaminant plume hot spot removal (Earth Tech, 1996a).

Non-promulgated advisories or guidance, referred to as “to-be-considered” (TBC) materials, may be used to determine cleanup levels when ARARs do not exist or when ARARs alone would not be sufficiently protective of human health and the environment. TBCs are not legally binding. However, if a TBC is chosen as a cleanup requirement, it becomes a performance standard with which the chosen remedy must comply. The selection of TBCs as performance standards, however, is discretionary and not mandatory. TBCs also are listed in Appendix C of the EE/CA (Earth Tech, 1996a).

Groundwater beneath Edwards AFB is designated as “MUN” (municipal) in the Lahontan Water Quality Board (LWQB) Basin Plan; therefore, ARARs and TBCs recommended in the EE/CA were established based on the assumption that all groundwater beneath and downgradient from Site 5/15 represents a potential source of drinking water. Established MCLs for public water systems were proposed as ARARs for the Site 5/15 Contaminant Plume. California state MCLs are more stringent than federal MCLs, and were proposed as TBCs for Site 5/15. No soil ARARs are available. However, the USEPA Region 9 (1995) PRGs and the CRWQCB (1989) designated levels for soil (i.e., the TDLs) are TBCs for site soils, and are considered protective of groundwater. The proposed cleanup goals for benzene and TCE (the primary chemicals of concern), respectively, were 1 and 5 g/L in groundwater (state MCLs) and 0.01 and 0.05 mg/kg in soil (LWQB TDLs).

3.3 AVAILABLE REGULATORY OPTIONS

As noted above, the cleanup goals recommended in the EE/CA were established based on the assumption that all groundwater beneath and downgradient from Site 5/15 represents a potential drinking water source. A water body is a source (or potential source) of drinking water only if it is in current domestic use, or will be available for use at some point in the future. Under certain circumstances, institutional controls (for instance, restrictions on the use of groundwater) may effectively preclude particular water uses. Although the Water Resource Board of the State of California has adopted a non-degradation policy for groundwater, adverse impacts on a body of water that may affect its potential uses are considered to occur not at the point of introduction of contaminants, but rather at points of exposure of potential receptors. In recognition of these facts, the framework of environmental regulation in recent years has evolved from strict application of numerical standards to the application of risk-based standards at individual sites, while incorporating careful consideration of site-specific factors and

potential use of resources, including land and water (American Society for Testing and Materials [ASTM], 1999).

Current conditions at Site 5/15 suggest that re-evaluation of cleanup goals for the site may be appropriate because the MCLs and TDLs proposed in the EE/CA for the primary chemicals of concern (benzene and TCE) may be technically infeasible to achieve (as described in detail in Section 4). Therefore, it is recommended that the Air Force apply for exceptions to the use of MCLs as cleanup goals for groundwater, which would also affect cleanup goals for soil. This strategy would be most appropriate for contaminated media beneath the source area, where free product exists.

Technical Impracticability Waiver

There are provisions in both federal and state regulations to apply for an exception to the application of MCLs as ARARs. In making exceptions for water use designation, the LWQB Basin Plan (1999) considers criteria listed in Regional Board Resolution No. 6-89-94. These criteria include conditions for a site where “there is contamination that cannot reasonably be treated for domestic use either by best management practices or best economically achievable practices”. Under the current regulatory framework, Site 5/15 appears to meet such criteria. Non-attainability of MCLs in groundwater could also be demonstrated under USEPA’s (1993) technical impracticability (TI) waiver protocol. ARARs may be waived by USEPA for any six of the reasons specified in the NCP (Comprehensive Environmental Restoration, Compensation, and Liability Act [CERCLA] 121[d][4]), including TI from an engineering perspective. The TI evaluation generally should include the following components, based on site-specific information and analyses (USEPA, 1993):

1. Specific ARARs or media cleanup standards for which TI determinations are sought.
2. Spatial area over which the TI waiver will apply.
3. CSM that describes site geology, hydrology, and groundwater contamination sources, transport, and fate.
4. An evaluation of the restoration potential of the site, including data and analyses that support any assertion that attainment of ARARs or media cleanup standards is technically impractical from an engineering perspective. At a minimum this should include:
 - a. A demonstration that contaminant sources have been identified and have been or will be removed and contained to the extent possible;
 - b. An analysis of performance of any ongoing or completed remedial action;
 - c. Predictive analysis of the time frames to attain required cleanup levels using available technologies; and
 - d. A demonstration that no other remedial technologies (conventional or innovative) could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable timeframe.

5. Estimate of cost of the existing or proposed remedy options, including construction and O&M costs.
6. Any additional information or analyses that USEPA deems necessary for the TI evaluation.

After a TI decision is made, USEPA (1993) requires that an alternative cleanup strategy be developed. As part of this alternate strategy, we would recommend that site-specific cleanup goals be developed for the affected media as part of a risk-based corrective action (RBCA). The RBCA process uses a tiered approach, which integrates site assessment and response actions with human health and ecological risk assessment, to evaluate the necessity for remedial action, and to tailor corrective actions to site-specific conditions and risks. Presented below is an evaluation of potential risk-based clean-up goals using the RBCA process.

3.4 Evaluation of Site-Specific Risk-Based Cleanup Goals

This section presents screening level risk-based media cleanup goals for benzene and TCE in soil and groundwater. The intent of presenting these screening level cleanup goals is to illustrate how site-specific cleanup goals may be developed using a risk-based approach and how these goals compare to cleanup goals proposed in the EE/CA. The risk-based goals developed for benzene and TCE and the cleanup goals proposed in the EE/CA are compared in Table 3.1. The risk-based goals were developed for a generic industrial land-use scenario similar to Site 5/15, which is consistent with the expected land-use for this site. Risk-based goals were established based on the following exposure assumptions:

- An onsite well will be used to supply water to be used for onsite irrigation purposes only (no consumption);
- Groundskeepers may be exposed through dermal contact to contaminants in extracted groundwater that is used for landscape irrigation. No other exposure routes are significant;
- Based on assumed attire, the hands, forearms, and lower legs will be the body parts dermally exposed;
- A groundskeeper will irrigate an average of one time per week for 50 weeks per year. The watering frequency in the warmer months may be 2 times a week, but in the winter this would be significantly less, averaging to approximately once a week for a given year; and
- The risk-based cleanup goals for benzene and TCE are based on a 1 in 1,000,000 (i.e., $1E-06$) excess cancer risk, as required by the LWQB Basin Plan.

The LWQB Basin Plan (1999) requires that cleanup goals in soil be protective of groundwater. Therefore, soil risk-based cleanup goals protective of groundwater were derived using the methods described in USEPA's (1996a and 1996b) *Soil Screening Guidance: User's Guide (EPA/540/R-96/018)* and *Technical Background Document (EPA/540/R95/128)*. These methods are consistent with the methods outlined in ASTM's

(1999) RBCA guidance. The soil screening levels are protective of the groundwater at risk-based levels reported in the first column of Table 3.1. Because contamination at Site 5/15 is found at depths greater than 10 feet, direct exposure pathways (e.g., soil ingestion by a construction worker) are incomplete and were not included in this evaluation. Details of the exposure assumptions, models, and input parameters used are presented in Appendix A.

Cleanup goals for benzene and TCE resulting from groundwater consumption under a generic industrial land-use scenario are also presented in Appendix A. These cleanup goals are only slightly greater than the MCLs and TDLs listed in Table 3.1. Therefore, an alternative remedial strategy for this site should also include land use restrictions that prevent groundwater consumption, because cleanup goals that would be protective of industrial groundwater consumption would most likely be technically impracticable.

TABLE 3.1
ALTERNATE RISK-BASED CLEANUP GOALS
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Contaminant	Alternate Risk-Based Cleanup Goals		Cleanup Goals Proposed in the EE/CA	
	Groundwater (µg/L)	Soil (mg/kg)	State MCL for Groundwater (µg/L)	Soil Total Designated Levels (mg/kg)
Benzene	514	4	1	0.01
TCE	1,260	14	5	0.05
EDB	0.4	0.003	0.05	0.0005

It should be noted that the risk-based cleanup goals presented in Table 3.1 are generic for industrial settings and do not represent actual site conditions. Site-specific risk-based cleanup goals for Site 5/15 should be developed in the ROD after gaining regulatory approval to proceed with a risk-based approach. The risk-based cleanup goals presented in Table 3.1 are based on USEPA's conservative default parameters and assumptions for the industrial exposure scenario.

In addition to EPA and CRWQCB regulations, Title 27 of the California Code of Regulations (CCR) includes guidelines to apply for concentration limits greater than background (CLGB). Even though the TI waiver for Site 5/15 would not apply to background levels, the Air Force should take into consideration the criteria noted in Title 27 in a TI waiver application in the state of California. The guidelines state that a CRWQCB can establish a CLGB only if the board finds that it is technologically or economically infeasible to achieve the background value for that constituent and that the constituent will not pose a substantial present or potential hazard to human health or the environment as long as the CLGB is not exceeded. To establish a CLGB for a constituent of concern, Title 27 states that a CRWQCB should consider the following factors on potential adverse effects on groundwater quality and beneficial uses:

- The physical and chemical characteristics of the waste at the site;
- The hydrogeological characteristics of the facility and surrounding land;
- The quantity of groundwater and the direction of groundwater flow;
- The proximity and withdrawal rates of groundwater users;
- The current and potential future uses of groundwater in the area;
- The existing quality of groundwater, including other sources of contamination or pollution and their cumulative impact on the groundwater quality;
- The potential for health risks caused by human exposure to waste constituents;
- The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and
- The persistence and permanence of the potential adverse effects.

SECTION 4

EVALUATION OF REMEDIAL SYSTEM

Section 3 describes the importance of understanding the remediation goals for the site, and, if necessary, how to begin the process of establishing more practical clean-up objectives. Commonly, a remediation system's effectiveness and efficiency are directly related to achieving these clean-up objectives. In some circumstances, such as Site 5/15, no final clean-up goals have been established and the "measuring stick" for system performance is ambiguous because of the focus of the system (i.e., source removal as opposed to total aquifer restoration).

Evaluating a system during the RPO process involves two phases:

Phase I – Annual performance evaluations to evaluate system performance to date, to recommend minor modifications to the system, and to assess whether a more involved evaluation is necessary (i.e., Phase II).

Phase II – A more rigorous review of the entire remedial decision and implementation process.

This section focuses on performing a Phase II review of the existing system (remedial decisions were evaluated in Section 3) leading to short-term recommendations and identifying long-term opportunities for improvement (Section 5).

4.1 EVALUATION OF PERFORMANCE CRITERIA

Performance criteria for any system should be viewed as measurable milestones on the road to achieving site cleanup objectives and site closure. These criteria are developed from modeling, estimates, or extrapolations made during the initial design stages and are used to estimate remediation timelines and anticipated progress. Performance criteria should be selected so that they can be evaluated against routinely collected data at the site and should be reviewed at least annually to assess system effectiveness/efficiency.

At Site 5/15, the primary objective of the IRA stated in the EE/CA (Earth Tech, 1996a) is to:

“...reduce the volume and concentration of hydrocarbon, solvents, and LNAPL contamination in the subsurface...and...cleanup all soil and groundwater contamination to acceptable health-based levels or to the extent technically feasible.”

Specific remedial action objectives (RAOs) of the IRA at Site 5/15, identified in the EE/CA, are to (Earth Tech 1996a):

1. Reduce the volume, concentration, and mobility of contaminants in the soil and groundwater at the “hot-spots.”
2. Reduce the contaminant concentrations in the soil and groundwater at Site 5 to levels that remove the potential for continued leaching of contaminants from the vadose zone to the saturated zone and remove the threat to human health and the environment to the extent that it is both technically and economically feasible.
3. Remove, to the extent practicable, mobile LNAPL to slow or prevent further contamination of soils and groundwater.
4. Install and operate a remediation system to treat soil and groundwater underlying Site 5.
5. Evaluate the technical feasibility of the selected IRA to clean up soil and groundwater at Sites 5 and 15 to acceptable health-based criteria.

In short, the objectives of the IRA are to remove as much source material in the hot spots as technically and economically feasible in an attempt to reduce the threat to human health and the environment. The amount of the source that should be removed to be protective of human health and the environment, and a definition for what is considered technically and economically feasible, are not specified in the EE/CA (Earth Tech, 1996a).

Therefore, as part of this RPO evaluation, measurable performance criteria for the DES were developed based on the objectives stated above. These performance criteria and the rationale for their selection are summarized in Table 4.1. Though these performance criteria may not have been the strict intent of the IRA, they provide a basis for evaluating the systems effectiveness and efficiency to date. These performance criteria could also be used to assess the system's technical and economical feasibility. These performance criteria originated from the rationale used in the EE/CA to justify the IRA (i.e., remove hot spots, which were considered to be contamination above TDLs in soil and LNAPL on the water table near Site 5).

No performance criteria were developed in this exercise for contaminant concentrations in groundwater because the restoration of groundwater quality was not the intent of this phase of the IRA.

4.2 EFFECTIVENESS/EFFICIENCY EVALUATION

System effectiveness refers to the ability of the system to achieve the remediation goals at a given site. Efficiency refers to the optimization of time, energy, and costs associated with achieving remediation effectiveness using a specific technology (Parsons ES, 1999). This section evaluates DES effectiveness to date by evaluating performance versus the criteria developed in Section 4.1, and assessing efficiency of the system by comparing performance with other similar systems.

The nature of the system at Site 5/15 lends itself to evaluating effectiveness/efficiency for the two phases of contamination that are being extracted:

TABLE 4.1
MEASURABLE PERFORMANCE CRITERIA
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Performance Criteria	Corresponding Remedial Action Objective	Rationale
1. Reduce soil concentrations within the hot-spot to below Total Designated Levels (TDLs) as calculated in the Site 5/15 EE/CA (Earth Tech, 1996a).	1, 2, 4, 5	<p>TDLs presented in the EE/CA are the contaminant concentrations in soil thought to be protective of underlying groundwater. Thus, achieving these criteria in soil would reduce the risk to human health and the environment.</p> <p>Contaminants of particular interest include benzene (TDL = 0.01 mg/kg) and trichloroethene (TDL=0.05 mg/kg). The volume of contaminated soils exceeding these concentrations is approximately 130,800 cubic yards, with a total mass of benzene and trichloroethene presently estimated at 5,327 lbs (Earth Tech, 1996a).</p>
2. Remove LNAPL at Site 5/15 to a thickness of less than 0.125 inch as measured in monitoring wells.	1, 2, 3, 4, 5	<p>The LNAPL present at Site 5/15 acts as a continuing source to the degradation of groundwater quality. Removal of LNAPL reduces this source and thus reduces risk to human health and the environment. The 0.125-inch thickness is considered the lowest measurable quantity of “free” product on a water table.</p> <p>The LNAPL volume at Site 5/15 has been estimated at 599,000 gallons (or 3,594,000 lbs assuming a 6 lb/gal density) at Site 5/15 (Earth Tech, 1996a). Product thickness ranged from 0.61 to 3.08 feet prior to system installation (Earth Tech, 1996a).</p>

- Vapor (includes the vapor extraction and treatment portion of the system and is intended to achieve Performance Criterion 1); and
- Liquid (includes the free-phase and dissolved contaminant extraction and treatment system and is intended to achieve Performance Criterion 2).

A comparison of performance criteria and current conditions is provided as Table 4.2.

Performance Criterion 1: Vapor

No soil sampling has been conducted since the DES was installed to assess the reduction in contaminant concentrations within the hot-spot attributable to the IRA.

TABLE 4.2
PERFORMANCE CRITERIA VERSUS CURRENT CONDITIONS
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

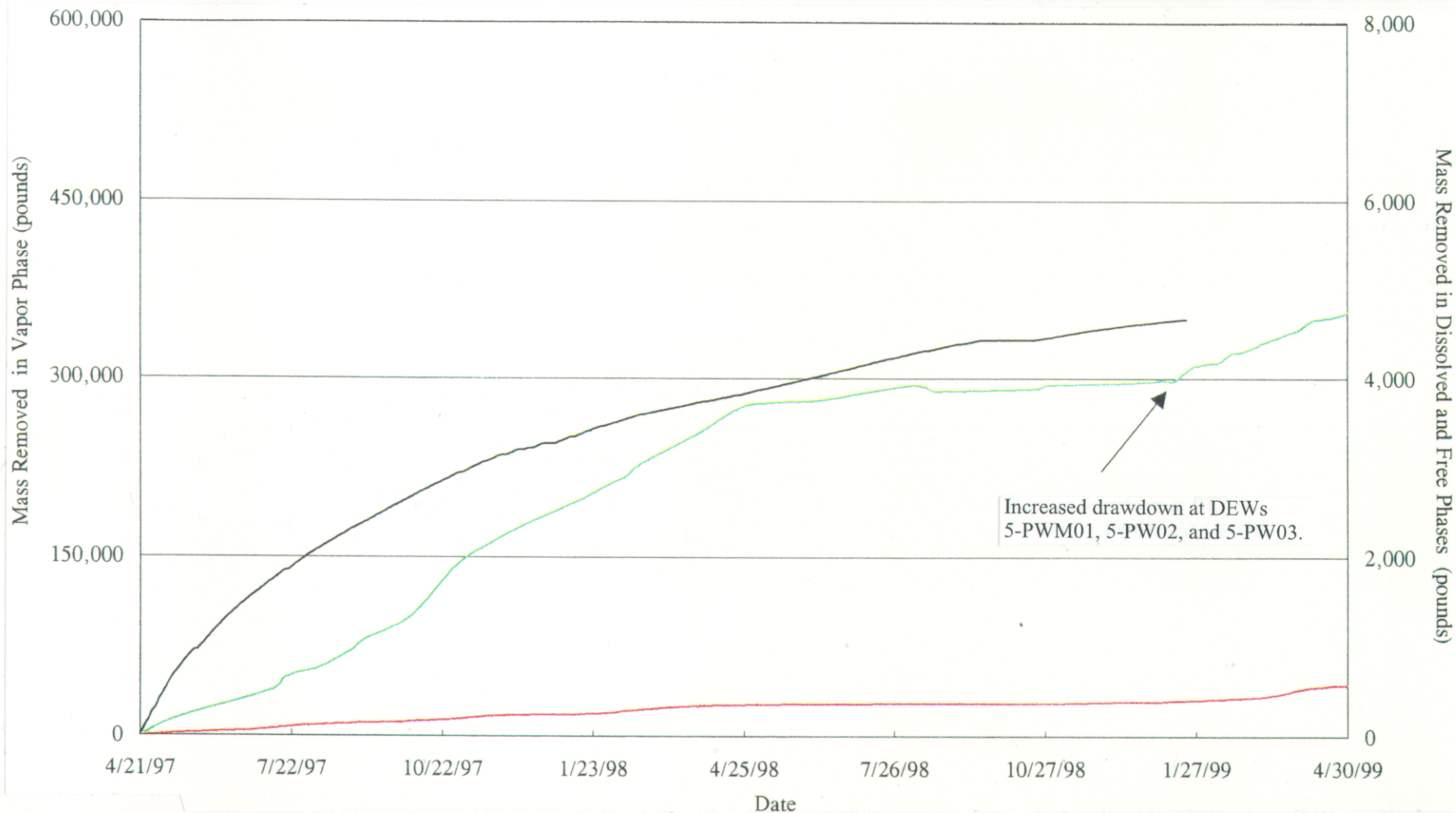
Criterion	Contaminant Phase	Measurable Quantities ^{a/}	Comparison ^{b/}	Percent Complete	Estimated Year Criterion is Met ^{c/}
1. Reduce soil concentrations within the hot-spot to below Total Designated Levels (TDLs), as calculated in the Site 5/15 EE/CA (Earth Tech, 1996a).	Vapor	5,327 lbs benzene and trichloroethene in Site 5 hot-spot	2,013 lbs benzene and trichloroethene (removed through April 1999)	38 percent	2017
2. Remove light nonaqueous-phase liquid (LNAPL) at Site 5/15 to a thickness of less than 0.125 inch, as measured in monitoring wells.	Liquid	889,000 lbs free product in hot-spot (Site 5) prior to IRA	5,171 lbs free product (removed through April 1999)	0.6 percent ^{d/}	2262 ^{d/}

^{a/} Earth Tech, 1996a.

^{b/} Earth Tech, 1999c and 1999d.

^{c/} Assume April 1999 removal rates remain constant throughout duration.

^{d/} Does not include entire Site 5/15 area free-product mass.



Notes:

Mass removal in vapor phase is not shown after January 22, 1999 due to analytical results suspected of being biased high.

**FIGURE 4.1
CUMULATIVE MASS OF
CONTAMINANTS REMOVED**

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

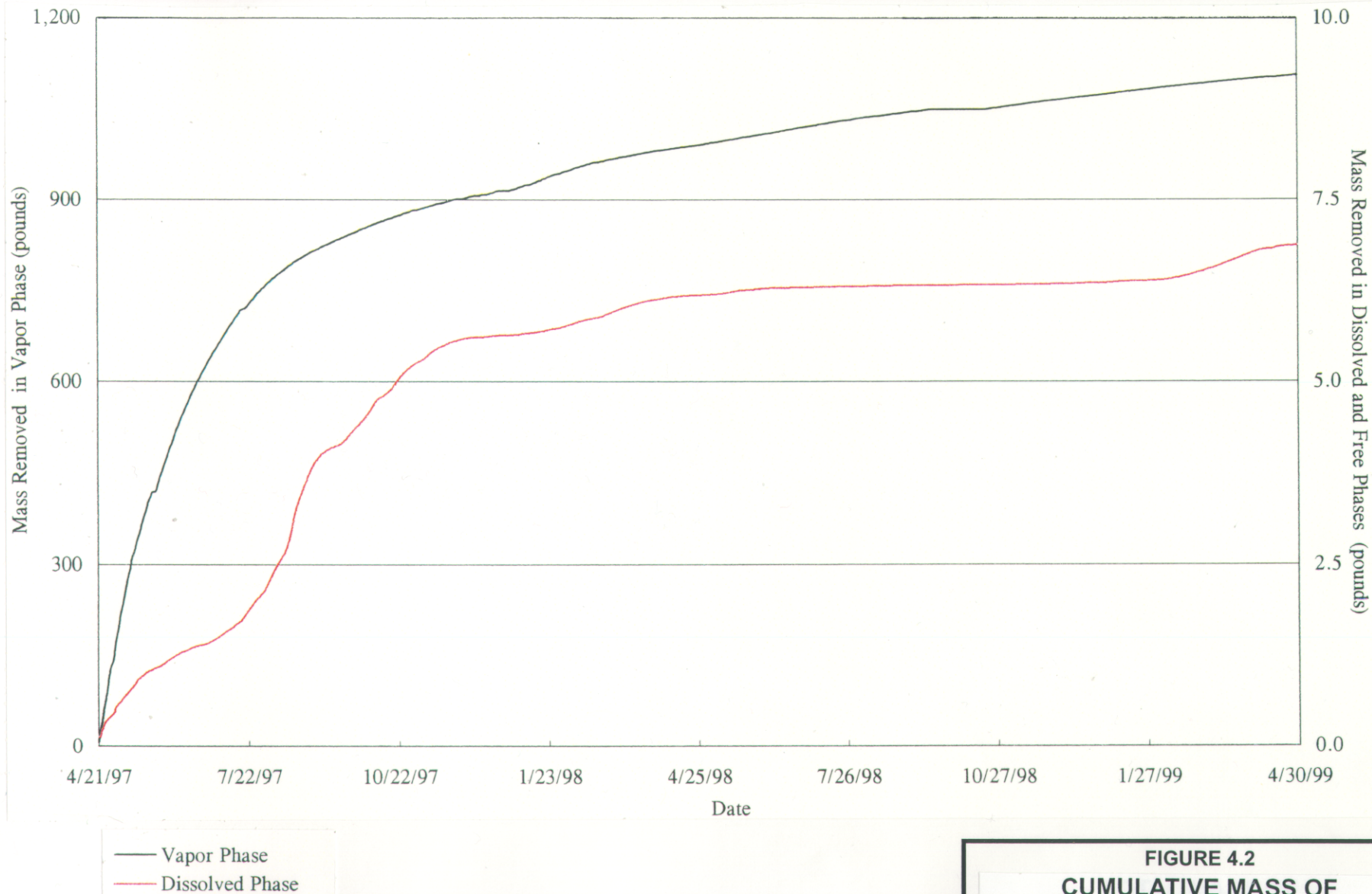
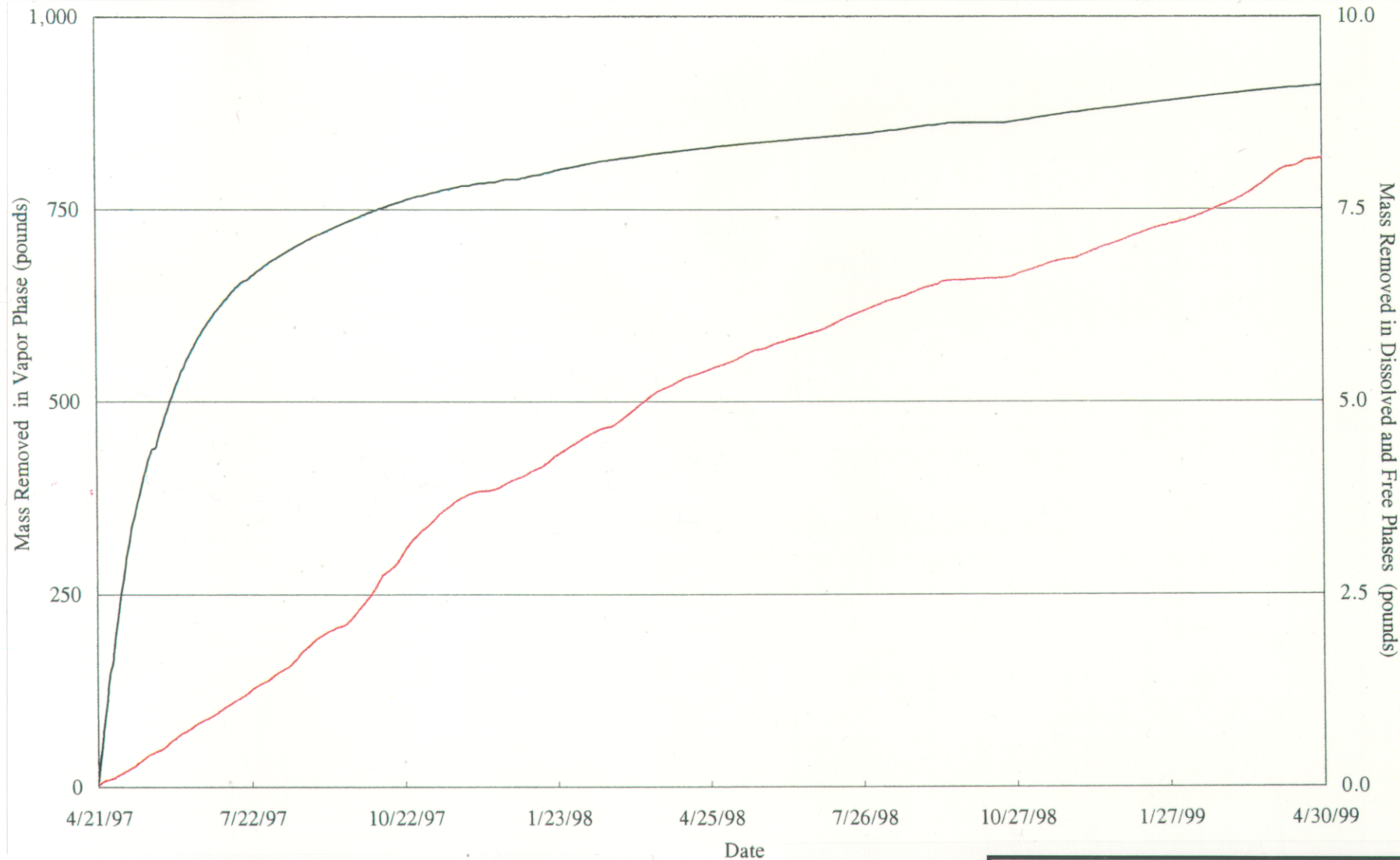


FIGURE 4.2
CUMULATIVE MASS OF
BENZENE REMOVED

Site 5/15 Contaminant Plume
 Remedial Process Optimization
 Edwards AFB, California

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— Vapor Phase
— Dissolved Phase

FIGURE 4.3
CUMULATIVE MASS OF
TRICHLOROETHYLENE REMOVED

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

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Thus, no direct comparison of past/current contaminant concentrations to TDLs can be made. However, the Site 5/15 EE/CA estimated that approximately 5,327 pounds (lbs) of benzene and TCE were present in the vadose zone hot-spot prior to implementation of the IRA (Earth Tech, 1996a). Through April 1999 (24 months of DES operation), approximately 2,013 lbs of benzene and TCE have been removed via SVE (Earth Tech, 1999c) (Figures 4.1 through 4.3). This represents approximately 38 percent of the total available benzene and TCE within the hot-spot as estimated in the EE/CA.

Mass removal rates have declined during the course of operation from 16 lbs per day (lbs/day) benzene and 19 lbs/day TCE in April 1997 to 0.27 lbs/day benzene and 0.23 lbs/day TCE in April 1999 (Earth Tech, 1999d). This represents more than a 98-percent decrease in mass removal rates since DES startup. The decrease in influent soil vapor concentrations is likely the result of diffusion-limited vapor flow in the silt/clay soils. Soil vapor concentrations of these COPCs were highest at the on-set of system operation, and declined steadily to asymptotic levels (Figure 4.4) (Earth Tech, 1999c). Assuming that 3,314 lbs (5,327 lbs – 2,013 lbs) of benzene and TCE remain in the hot-spot and that the DES maintains its current removal efficiency, the estimated time to complete source removal would be 18-years.

Given the amount of benzene/TCE mass removed in the vapor phase during 24 months of operation (approximately 38 percent of total estimated mass in the hot spot prior to DES startup), and the estimated time to complete source removal under the current conditions (18 years), the current system will not be effective in achieving performance criterion 1 in the 7-year schedule of the IRA. If current vapor-phase COPC removal rates are maintained, 72 percent of the estimated benzene and TCE mass would be removed during the 7 year operating period. It is important to note the estimated time frame to achieve performance objectives (18 years) is most likely underestimated and percent complete at the end of the 7-year schedule is most likely overestimated because of the continued decrease in removal efficiencies (the most available contamination has already been removed). Conversely, removal of 100 percent of the benzene and TCE mass in the vadose zone will not be necessary to achieve TDLs.

This vapor system efficiency of removing contaminant mass was compared to that achieved with similar treatment systems at other sites (Table 4.3). As indicated in the table, the removal rates and costs associated with the Site 5/15 DES system are superior to case studies provided in a recent USEPA (1999) report on multi-phase extraction systems. The effectiveness of the Site 5/15 DES is enhanced by the fact that LNAPL and grossly contaminated soils are present in the treatment area, which permits higher removal rates and lower costs than typically can be achieved at sites without an LNAPL source.

Performance Criterion 2: Liquid

Prior to implementation of the IRA, product thickness in monitoring wells ranged from 0.61 to 3.08 feet. After approximately 24 months of remediation (through April 1999), product thickness ranged from 0.10 to 9.1 feet (Earth Tech, 1999d). No noticeable decrease in the estimated areal extent of free product at the hot-spot has occurred. Based on measured product thicknesses and the areal extent of the LNAPL before and after IRA implementation, no significant decrease in product thickness or extent can be attributed to the IRA.

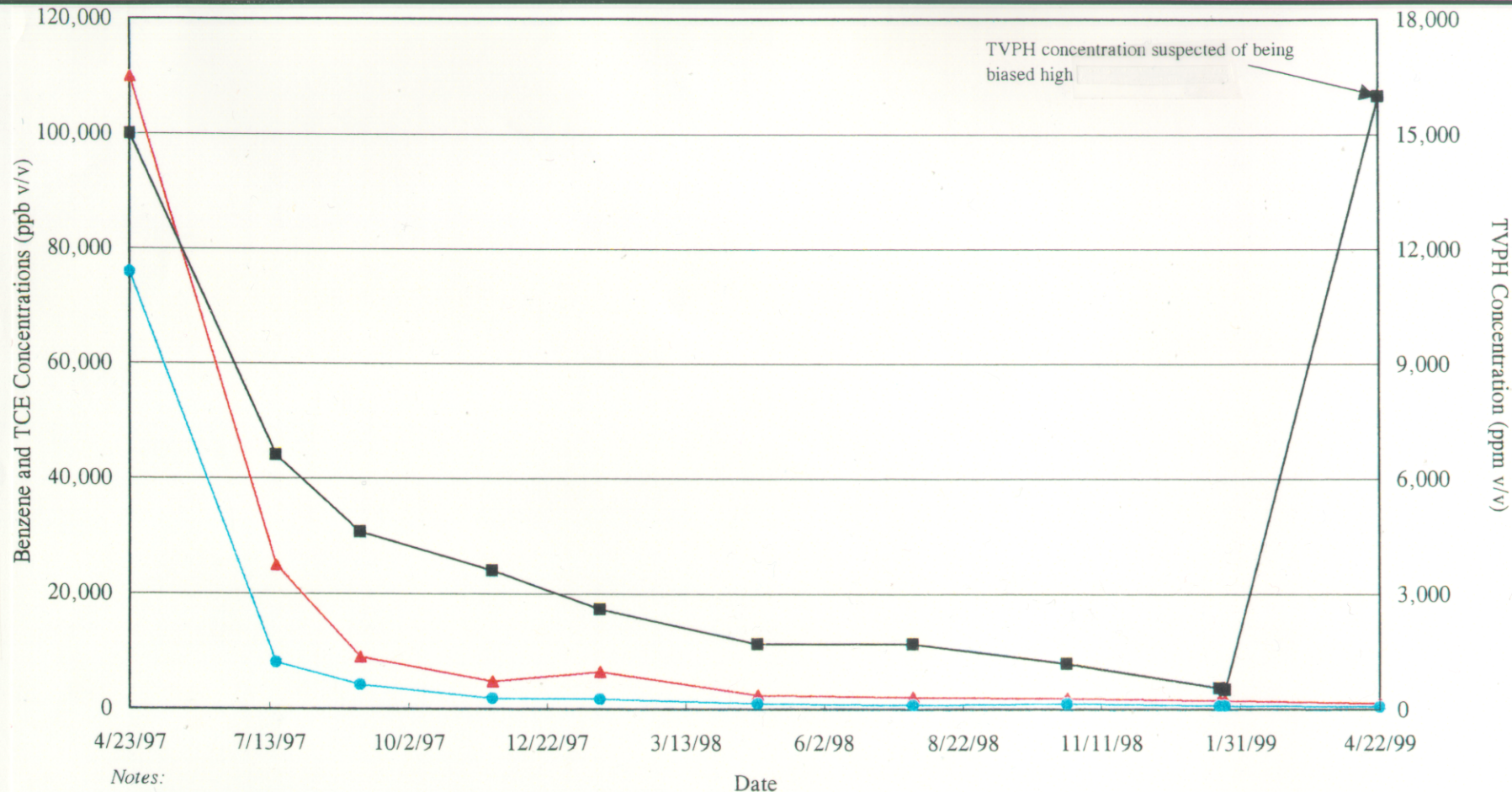


FIGURE 4.4
CONCENTRATIONS OF
CONTAMINANTS IN VAPOR PHASE
 Site 5/15 Contaminant Plume
 Remedial Process Optimization
 Edwards AFB, California
PARSONS
 PARSONS ENGINEERING SCIENCE, INC.
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TABLE 4.3
TREATMENT SYSTEM COMPARISON
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Parameter	Site 5/15	Defense Supply Center	328 Site	Tinkhams's Garage
Vapor ^{a/}				
Days of Operation ^{b/}	651	320	544	311
Total Mass Removed (lb organics)	350,597	117	801	48.25
Mass Removal Rate (lb organics/day) ^{c/}	538	0.4	1.5	0.2
Cost Per Mass Removed (\$/lb organics) ^{d/}	\$2.40	\$1,415	\$530	\$15,544

Parameter	Site 5/15	Skimming	Single-Pump Drawdown	Bioslurping
Liquid (free-product recovery) ^{e/}				
Total Mass Removed (lb organics)	5,171	-	-	-
Mass Removal Rate (lb organics/day) ^{c/}	8.0	18.7	27	127
Cost Per Mass Removed (\$/lb organics) ^{e/}	\$171	\$56	\$43	\$9.30

^{a/} Data for three sites compared to Site 5/15 vapor system (through January 1999) from *Multi-Phase Extraction: State-of-the-Practice* (USEPA, 1999). Where variations in site characteristics and system design, installation and operation do not allow a direct comparison of sites, the data are suitable for a qualitative comparison.

^{b/} For Site 5/15 based on approximate calendar days through January 1999. Other sites as reported.

^{c/} Average removal rate based on mass removed through reporting period divided by days of operation.

^{d/} Based on cost divided by mass of organics removed during days of operation for Site 5/15 (see Section 4.3 for Site 5/15 cost evaluation). Other site data are presented as reported. Costs for vapor and liquid treatment systems were assumed as a 50:50 ratio.

^{e/} Data for comparison to Site 5/15 liquid recovery system (through April 1999) from *Engineering Evaluation and Cost Analysis for Bioslurping Initiative* (Battelle, 1997).

The mass of product at Site 5, which is the primary focus area of the removal action, has been estimated to be as much as 889,000 lbs (Earth Tech, 1996a). Through April 1999, the liquid treatment system had recovered approximately 5,171 lbs of free-phase and dissolved-organics (Figure 4.1) (Earth Tech, 1999d). Based on these estimates, 0.6-percent of the estimated total contaminant mass of LNAPL at Site 5 has been removed.

Mass contaminant removal rates in the dissolved and free phases remained relatively constant during DES operations through April 1998. Subsequent measurements of mass removal rates have shown a significant decline in free-phase product removal rates. System adjustments (i.e., increased pumping rates from some wells) made during the 3-month period ending April 1999 resulted in increased removal efficiencies. As of April 1999, removal rates for both the dissolved and free-phase contaminants were approximately 9.2 lb/day. Assuming that 883,829 lbs (889,000 – 5,171 lb) of free-phase product remains, and that the system maintains its April 1999 removal efficiency, the timeframe for removing the LNAPL at Site 5 would be approximately 263 years (Table 4.2). This does not include the time required to remove LNAPL from all of Site 5/15 or restore the groundwater quality to MCLs. It should be noted that the April 1999 product recovery rates were almost three times greater than those measured in January 1999 because of the reconfiguration of the DES. It is unlikely that these rates can be maintained for a sustained period, resulting in a source removal time greater than that estimated.

The relatively small amount of contaminant mass removed during the first 24 months of DES operation (0.6 percent) and the estimated time to completion (263 years) indicate that the current system will not meet performance criterion 2 within the 7 years of scheduled operation. In fact, if current removal rates, which are likely to decline, are maintained, only 2.5 percent of the estimated mass (using the mass of free-product at Site 5) would be removed during the scheduled 7-year operating period (only 0.9-percent of total recoverable mass from the entire Site). It should be noted that the Base is preparing to implement a work plan, *Site 85 Free Product Removal Pilot Tests Work Plan* (Earth Tech, 1999) that will better define the extent, magnitude, and recoverability of free-product in the Site 5/15 vicinity, which will provide better estimates for performance criterion evaluation.

The Site 5/15 free-product recovery system (liquid) has a lower removal rate and higher unit cost in comparison to those achieved at other sites using other free-product recovery methods, based on data provided in *Engineering Evaluation and Cost Analysis for Bioslurper Initiative* (Battelle, 1997). This evaluation suggests that altering product recovery methods at Site 5/15 could increase removal rates but would not significantly shorten the total time required to meet performance/cleanup objectives.

Vapor vs. Liquid

As suggested by data presented in Table 4.3, the vapor removal system is significantly more effective than the liquid recovery system at removing contaminant mass from the subsurface at Site 5/15. SVE stimulates high mass-transfer rates (from LNAPL, dissolved, and sorbed contaminant forms into vapor) than product recovery and typically has fewer geological constraints than product recovery, which allows for higher extraction rates. At Site 5/15, the liquid system has recovered only 1.5 percent of the mass of the

vapor phase (Table 4.2). This leads to dramatically increased costs per pound of contaminant removed when expenses are separated by phase.

The Base recognized the inefficiency of the product-recovery system early during the IRA operation and evaluated alternative LNAPL and liquid phase recovery techniques (Earth Tech, 1997a). Air sparging was one technique selected for pilot testing, which was conducted in January 1999. The results of the test were inconclusive, and longer-term testing was recommended.

The review of the IRA at Site 5/15 has mixed results. The vapor recovery system has removed a considerable amount of mass from the vadose zone and volatile portion of the LNAPL during the first 2-years of operation but is showing signs of maturation. The influent concentration of benzene and TCE has reached low, asymptotic levels, which has resulted in a significant decrease in the system's performance. Short-term recommendations to increase influent concentrations and corresponding mass-removal rates are provided in Section 4. The liquid system is clearly not adequate to achieve performance criterion 2, which is most likely technically impracticable to achieve using the best available technology (e.g., air sparging, bioslurping, etc.). The inefficiency of the liquid recovery system suggests that it should be continued only if it has a noticeable beneficial impact on the efficiency of the vapor system (i.e., creates sufficient drawdown to expose highly contaminated soils at the capillary fringe).

4.3 COST EVALUATION

Capital and annual OM&M costs for the DES at Site 5/15 are summarized in Table 4.4. Supporting cost calculations are provided in Appendix G. Program monitoring costs are addressed in Section 4.4.

Capital and OM&M costs through April 1999 for the Site 5/15 treatment system total approximately \$1.8 million. Total actual dollars spent over the scheduled 7-year duration of the IRA are projected at \$3.6 million. Annual OM&M costs (\$365,300/year) consist mainly of labor (40 percent), utilities (electrical and fuel, which are not currently metered) (24-percent), and analytical (15 percent). The costs associated with each phase of treatment (vapor or liquid) could not be separated from the total. However, it is assumed that a least one-half the cost is associated with the liquid treatment system because of the number and complexity of system components involved (e.g., air compressor, oil/water separator, equalization tank, air stripper, etc.). Cost per unit of contaminant mass removed is significantly greater for the liquid system (\$171/lb VOCs) than the vapor system (\$2.40/lb VOCs). The OM&M unit costs for both vapor and liquid phase removal have been stable throughout the project (Figure 4.5).

Cumulative cost versus pounds of mass removed are illustrated in Figure 4.6. Over the first 12 months of operation the cost curve remained relatively flat. After VOC removal efficiencies started to decline subsequent to the initial 12-month operating period, the slope of the unit cost curve increased, and is projected to continue to increase over the next 5 years (assuming the current removal rates remain the same). As can be seen on Figure 4.6, it will become increasingly more costly for each pound of source mass removed from the site, almost tripling the cost to remove source mass over the next 5-years.

TABLE 4.4
COST SUMMARY FOR OPERATION, MONITORING, AND MAINTENANCE
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AFB, CALIFORNIA

Item	Cost
Pre-Installation Estimates ^{a/}	
Estimated Capital	\$1,254,100
Estimated Annual O&M	\$352,300
Estimated Total (over 7 years) ^{b/}	\$3,720,200
Actual Costs	
Capital and Year 1 O&M ^{c/}	\$1,408,675
Estimated Annual O&M ^{d/}	\$365,300
Projected Total (additional 6 years or 7 years total) ^{b/}	\$3,600,475
Projected Total (additional 29 years or 30 years total) ^{b/}	\$12,002,375
Cost Per Mass of Source Removed	
Vapor: Cost Per Pound Total Organics Removed	\$2.40
Vapor: Cost Per Pound Benzene Removed	\$803
Vapor: Cost Per Pound TCE Removed	\$977
Liquid: Cost Per Pound Total Organics Removed	\$171

^{a/} Earth Tech, 1996a.

^{b/} Actual dollars.

^{c/} Rowans, 1999. Includes installation, 1-year operation and maintenance, and preparation of treatability study report. Appendix B.

^{d/} Rowans, 1999. Based on 1999 funding request from Base (USAF, 1999) plus \$89,200 for electricity and fuel (as estimated in the EE/CA). Does not include well field monitoring program. Appendix B.

^{e/} Appendix B.

4.4 MONITORING PROGRAM EVALUATION

Designing an effective monitoring program involves locating groundwater monitoring wells and developing a site-specific groundwater sampling and analysis strategy. The monitoring program should be designed to monitor plume migration over time and to verify that remediation processes are occurring at rates sufficient to protect potential downgradient receptors. The design of the monitoring program should include consideration of existing exposure pathways, as well as exposure pathways arising from potential future use of the groundwater.

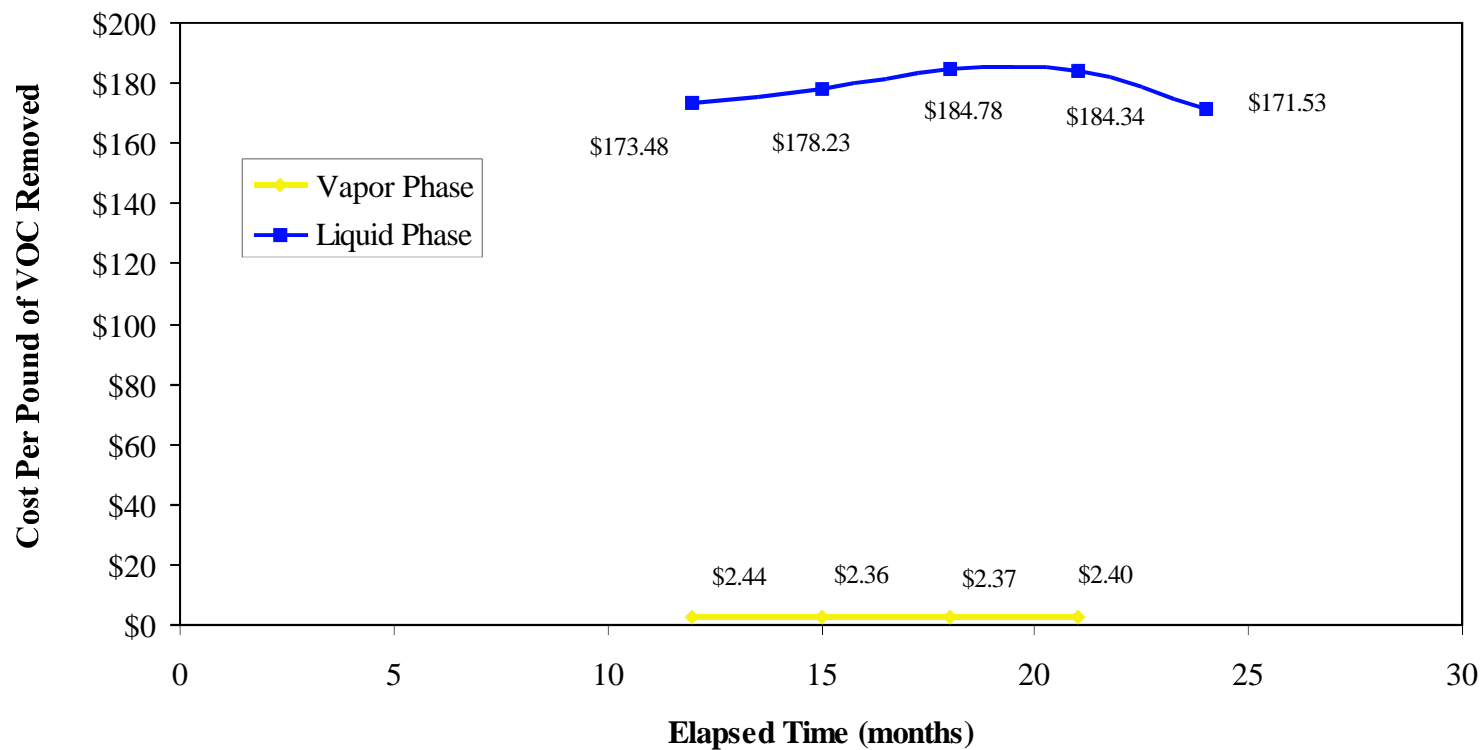


FIGURE 4.5
UNIT COST FOR
TREATMENT SYSTEM
Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

Parsons
parsons engineering science, inc.
Denver, Colorado

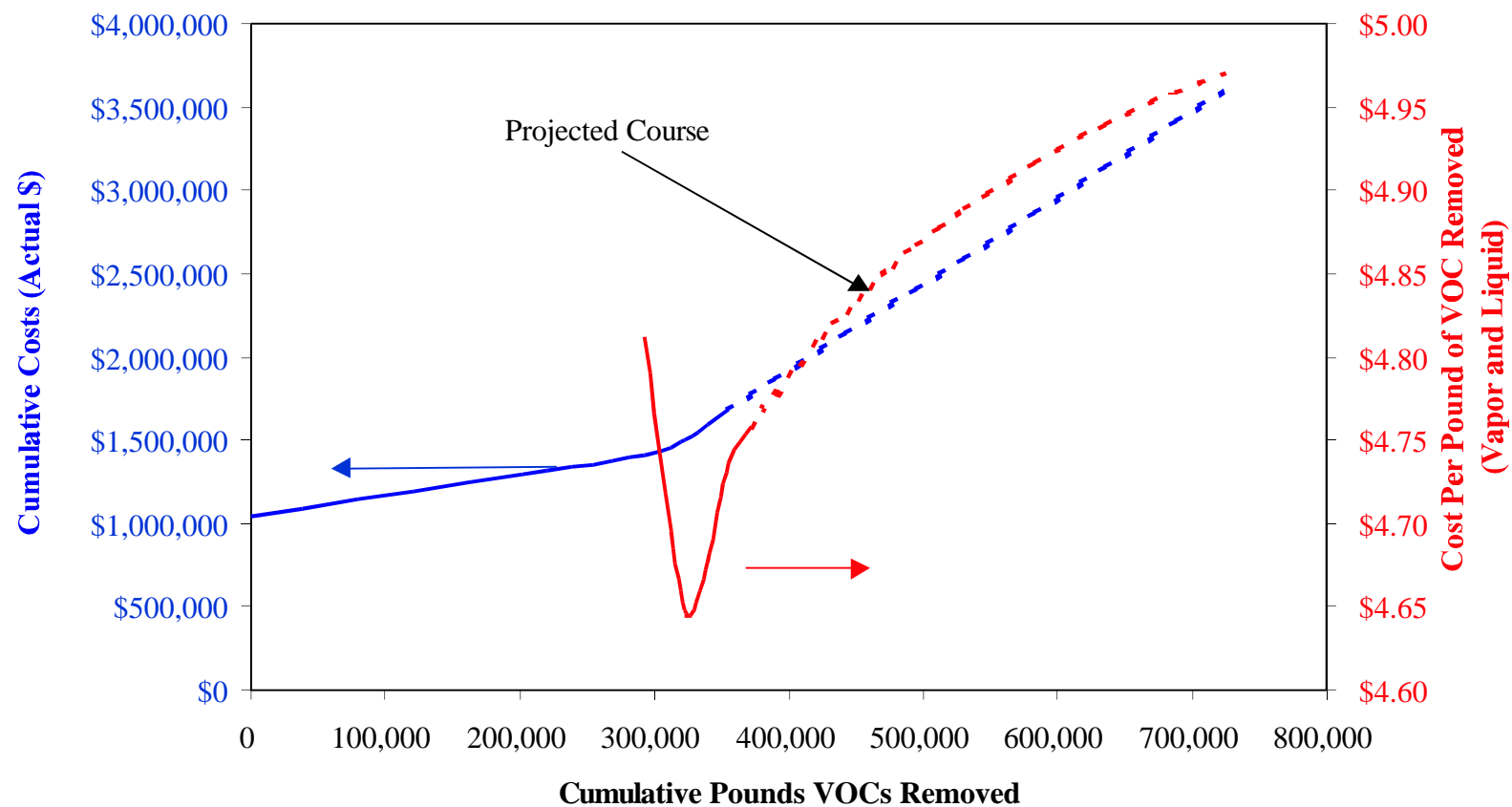


FIGURE 4.6
PROJECTED CUMULATIVE AND UNIT
COST FOR TREATMENT SYSTEM

Site 5/15 Contaminant Plume
 Remedial Process Optimization
 Edwards AFB, California

Parsons
 parsons engineering science, inc.

Denver, Colorado

Performance monitoring wells, located upgradient, within, and just downgradient of the plume verify the system effectiveness relative to the performance criteria. Long-term monitoring of these wells also provides data to detect migration of the plume and define trends in concentration over time. A contingency monitoring well downgradient of the plume is used to ensure that the plume is not expanding past the containment system and to trigger a contingency remedy if contaminants are detected. Primary factors to consider are (at a minimum) distance to potential receptors, groundwater seepage velocity, types of contaminants, aquifer heterogeneity, surface water impacts, and the effect of the remediation system. These factors will influence well spacing and sampling frequency. Typically, the faster the seepage velocity and the shorter the distance to receptors, the greater the sampling frequency. One of the most important purposes of long-term monitoring is to confirm that the contaminant plume is behaving as predicted. Visual and statistical tests can be used to evaluate plume stability. The historical data for groundwater remediation systems should demonstrate a clear and meaningful downward trend at appropriate monitoring points.

System performance monitoring data are used to assess the effectiveness of the DES in remediating soil and groundwater at the Site 5/15 Contaminant Plume, document mass removal rates and total mass removed, and document O&M concerns or problems that may affect long-term reliability and operating costs.

Currently, long-term groundwater monitoring samples are being collected at 56 monitoring points throughout the Site 5/15/85/14 plume. Groundwater samples from all wells are analyzed for VOCs by method SW8260M. TVPH (SE8015VB), TEPH (SE8015EB), and ethylene dibromide (E504.1) are analyzed only in the 42 wells in the Site 5/15/85 area. Table 4.5 summarizes the costs for each round of groundwater monitoring. Assuming that semiannual monitoring would continue for an additional 30 years, the cost of the current long-term monitoring (assuming no inflation in costs) is \$2.5M.

It was noted during evaluation of the TCE plume that there are no contingency monitoring wells downgradient of the Site 14 treatment system along the axis of the groundwater flow path. Contingency wells are intended to trigger implementation of a contingency remedy. It is recommended that a new monitoring well be installed approximately 500 feet southeast of well 14-M03. This well would identify if TCE were to migrate past the Site 14 containment pump and treat system.

4.5 ALTERNATE TECHNOLOGY EVALUATION

Given the magnitude, extent, and depth of the hot-spot at Site 5/15, few alternatives are available for source removal beyond what is currently being applied. Vapor extraction for remediation of the soil hot-spot is one of the most aggressive and practical approaches which can be applied at the site (given the depth [24 to 50 feet bgs], excavation is impractical). A somewhat less aggressive approach would be the use of bioventing to remediate the petroleum hydrocarbons. However, bioventing would not effectively deal with the TCE remaining in the soil and thus would not meet the objectives of the IRA.

Limited options are available for LNAPL recovery. DES is considered one of the most aggressive options. Air sparging, as is being evaluated by the Base, is a second

TABLE 4.5
ESTIMATED COSTS FOR CURRENT GROUNDWATER MONITORING PROGRAM^{a/}
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
3 people for 12 days at \$60/hr	288	hours	\$	60.00	\$ 17,280.00
Labor for data validation and data management					
2 people for 4 days at \$60/hr	64	hours	\$	60.00	\$ 3,840.00
Laboratory Analyses					
VOCs by method SW8260	56	samples	\$	120.00	\$ 6,720.00
Diesel Range hydrocarbons by Method SW8015	42	samples	\$	65.00	\$ 2,730.00
Volatile Range Hydrocarbons by Method SW8015	42	samples	\$	60.00	\$ 2,520.00
Ethylene dibromide by E504.1	42	samples	\$	78.00	\$ 3,276.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O ₂ /CO ₂ , etc.)	12	days	\$	400.00	\$ 4,800.00
Vehicle Rental (2 vehicles for 12days)	24	days	\$	45.00	\$ 1,080.00
Miscellaneous Field Supplies					\$ 100.00
SUBTOTAL COST				\$	42,346.00
Long-Term Monitoring for 30 years of semiannual sampling					x60
TOTAL COST				\$	2,540,760.00

^{a/} Estimated by Parsons ES based on current sampling program.

option given the ineffectiveness of the single-pump draw-down methods of DES. However, air sparging is not a proven technology for removing free product. It is best suited to remediate dissolved groundwater contamination in a homogeneous aquifer. Bioslurping, as can be seen in the comparison made in Table 4.3, can be a cost-effective means of LNAPL recovery. This would require replacing multiple pneumatic pumps with bioslurping tubes and a single liquid-ring pumping system. No other options can be identified for LNAPL recovery at the site.

For both the source removal and total site remediation, as described in Section 3.4, a risk-based approach should be evaluated when establishing the final cleanup goals of the site. The final cleanup goals will determine the type and intensity of future remedial actions at Site 5/15.

SECTION 5

RECOMMENDATIONS

Section 3 and 4 provide an overview and evaluation of the remedial decision process and system performance to date. Based on these reviews, both short-term recommendations and long-term opportunities can be made and identified to immediately impact system performance (short-term) and provide a frame-work for the direction of the site in the future (long-term).

5.1 SHORT-TERM RECOMMENDATIONS

System Improvements

Based on the current performance of the DES system and in comparison with other DES systems, the existing vapor recovery system has been efficient at removing contaminant mass. In comparison to other technologies, the liquid or free-product recovery system has been less than optimal. As discussed in Section 4, the technical practicability of the IRA to achieve the clean-up criteria outlined in Section 3.2 or the performance criteria outlined in Section 4.1 within a reasonable timeframe is doubtful. The primary benefit of continuing the IRA is to collect additional data, which can be used to support a TI waiver near the source area.

In an attempt to add value to these data collection efforts, the following recommendations are made regarding optimization testing of the system over a 9-month period:

Recommendation No. 1: Temporarily (approximately 9 months) discontinue the operation of the liquid recovery system.

Rationale: As discussed in Section 4, the liquid recovery system has removed just 1.5-percent of the contaminant mass that the vapor recovery system has removed in the same time period. In addition, based on the performance to date, the free product recovery system will not be effective at meeting the cleanup or performance objectives. Thus, the primary benefit of continued operation of the liquid system is to expose contaminated soils to vapor flow through the drawdown of the water table. However, no data was received to support that localized drawdown near the DEWs is significantly improving the vapor recovery rates. A temporary halt to liquid recovery will enable the following to occur:

- *Observe if there is a reduction in vapor phase removal rates as a result of discontinued liquid phase system operation;*

- *Reduce the volume of vapor being processed by the catalytic oxidizer by just under 50-percent (i.e., no off-gas from the LPAS), thereby reducing supplemental fuel (i.e. natural gas) costs.*
- *Reduce service time required of the liquid system (e.g., cleaning the biomass from the oil/water separator and equalization tank, etc.).*
- *Reduce the overall cost by lowering labor, utility, and analytical expenses (see Section 5.1.1).*

Note: The limited screen length above the static water table (5 feet) may limit the effectiveness of this recommendation.

Recommendation No. 2: Temporarily (3-months) reduce the flow-rate and vacuum at each active extraction well (3-months after implementation of Recommendation No. 1).

Rationale: Based on the last quarterly report (through April 1999) it appears that vapor recovery is being conducted with 11 extraction wells at a total combined flow-rate of approximately 700 to 800 scfm at a vacuum of 40 to 80-inches of water column. The concentration of contaminants in the influent vapor stream has reached an asymptotic level that suggests diffusion limitations are controlling mass recovery rates. By reducing the flow-rates and vacuums at each extraction well the following will occur:

- *Slow the exchange of vapors in the subsurface which will allow more time for mass-transfer of contaminants to occur. This will increase the contaminant concentration in the vapor stream and could reduce off-gas treatment costs;*
- *Reduce groundwater upwelling that occurs with vapor extraction which can have a detrimental effect on vapor recovery by making inaccessible some contaminated soils;*
- *Evaluate whether the lower flow-rates and vacuums provide a sufficient radius of influence surrounding the hot-spot;*
- *Reduce the volume of soil vapor being processed by the catalytic oxidizer, thereby reducing supplemental fuel costs.*
- *Reduce the overall cost by lowering utility costs (see Section 5.1.1).*

Recommendation No. 3: Temporarily (3-months) cycle between extraction wells (3-months after implementation of Recommendation No. 2).

Rationale: Cycling between wells is intended to achieve the same benefits (particularly lower overall flow rates) as Recommendation No. 2. This recommendation could be implemented subsequent to implementation and testing of Recommendation No. 2.

Monitoring Program Improvements

It was estimated that the media-monitoring program would cost approximately \$1.7 million over a 20-year period. The number of wells currently sampled during each semiannual event and the frequency of sampling was reviewed as part of the RPO evaluation. It is recognized that the sampling frequency should be appropriate to detect migration of the plume over time to protect potential receptors and to define trends in analyte concentrations. A short-term opportunity exists to revise the media-monitoring program and still provide sufficient data to monitor changes in plume extent and confidence in protecting receptors.

Recommendation No. 4: Reduce the frequency of sampling from semiannual to annual, and reduce the number of wells sampled for the long-term groundwater monitoring from 56 to 16. In addition, the analyses for gasoline and diesel range hydrocarbons are not necessary and should be eliminated. This reduction would not impact IRA monitoring activities.

Rationale: Because there are no current or potential receptors imminently at risk through exposure pathways, and the contaminant concentrations are generally decreasing (Figure 2.4), the semiannual frequency is deemed to be excessive. The available historical data provide a sufficient baseline for understanding plume trends. The groundwater velocity, determined to be 42 feet per year (Earth Tech 1996f), is sufficiently slow that no significant changes will occur to the plume extent that would cause concern to potential receptors over a one year period.

The spatial distribution of the current sampling points was reviewed, keeping in mind that it may not be appropriate or necessary for long-term monitoring to sample all wells installed during site characterization. It was determined that fewer wells could be sampled and still provide sufficient data to monitor plume migration, configuration, and concentration trends. Table 5.1 lists the wells recommended for sampling and Figure 5.1 shows the spatial distribution of the recommended sampling locations (including a recommended confirmatory monitoring well described in Section 4.4)

In addition, the analyses for gasoline (i.e., SW5030/LUFT Mod 8015 [TVPH]) and diesel range hydrocarbons (i.e., SW3510/LUFT Mod 8015 [TEPH]) are interesting, but are not necessary. There are no regulatory levels or ARARs for these constituents for compliance monitoring.

5.1.1 Cost Impact

System

Recommendation No.'s 1 and 3 have the largest long-term cost impact to the operational budget of the IRA system. These impacts were projected for the five years remaining in the project based on certain assumptions, which can be found in Appendix B. As is shown on Figure 5.2, without implementing any recommendations, the total projected costs in actual dollars at the end of the 7-year period would be approximately \$3.6M. If recommendation No.'s 1 and 3 were implemented, total project costs in actual

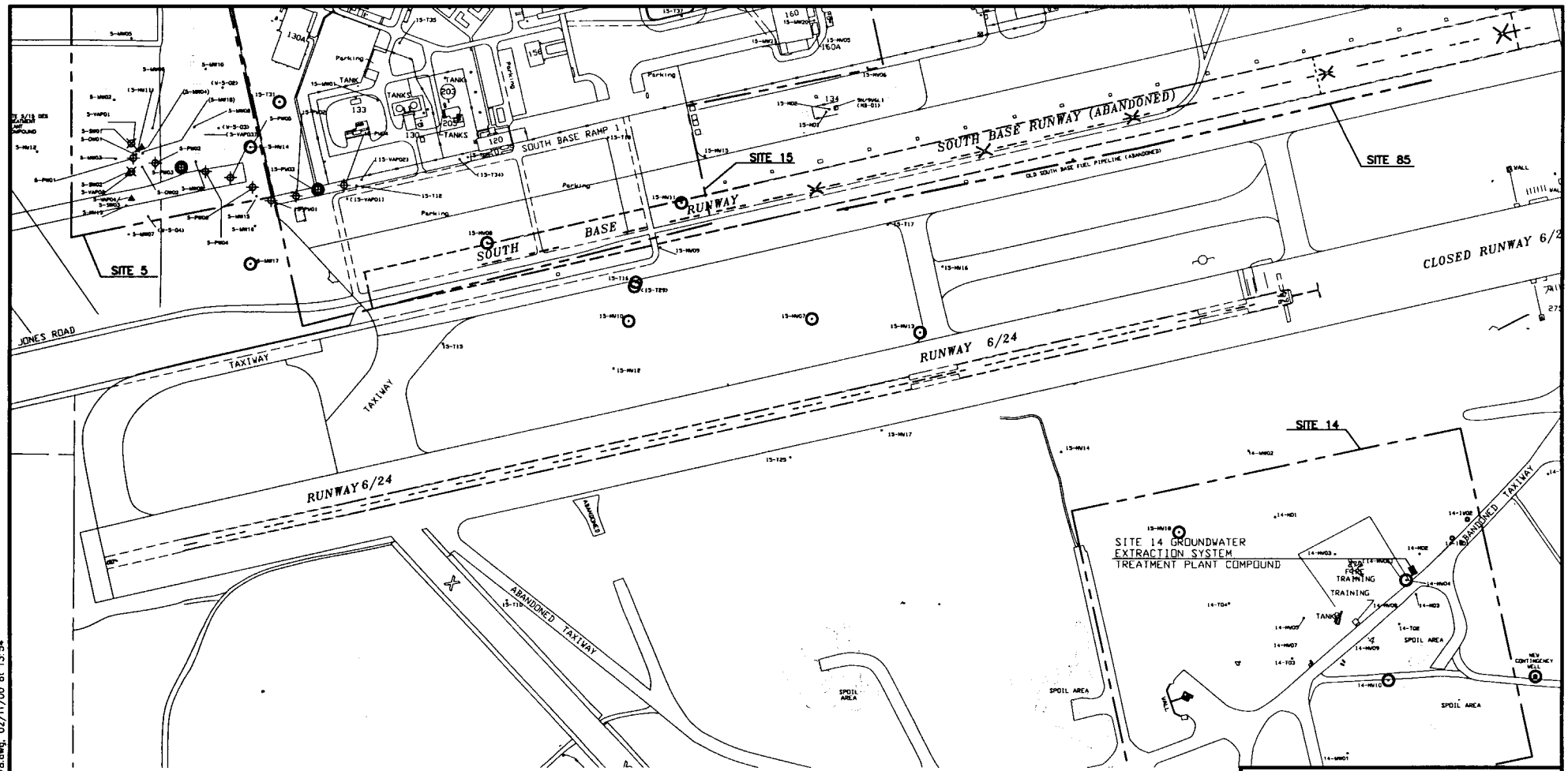
TABLE 5.1
RECOMMENDED LONG-TERM MONITORING PROGRAM
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Well ID	Analyses
5-PW03	VOCs (SW8260) and EDB (E504.1)
5-MW14	VOCs (SW8260) and EDB (E504.1)
5-MW17	VOCs (SW8260) and EDB (E504.1)
15-T31	VOCs (SW8260) and EDB (E504.1)
15-PW03	VOCs (SW8260) and EDB (E504.1)
15-MW08	VOCs (SW8260) and EDB (E504.1)
15-T16	VOCs (SW8260) and EDB (E504.1)
15-T29	VOCs (SW8260) and EDB (E504.1)
15-MW11	VOCs (SW8260) and EDB (E504.1)
15-MW07	VOCs (SW8260) and EDB (E504.1)
15-MW13	VOCs (SW8260) and EDB (E504.1)
15-MW18	VOCs (SW8260) and EDB (E504.1)
14-MW04	VOCs (SW8260) and EDB (E504.1)
14-MW06	VOCs (SW8260) and EDB (E504.1)
14-MW10	VOCs (SW8260) and EDB (E504.1)
New Contingency Well	VOCs (SW8260) and EDB (E504.1)

VOCs = Volatile Organic Compounds

EDB = Ethylene Dibromide

S:\ES\cod\AFCEE\734429\Edwards\98dm0678.dwg, 02/11/00 at 13:54

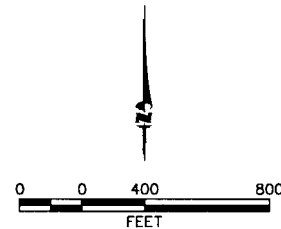


LEGEND

- PROPOSED NEW CONTINGENCY WELL
- EXISTING MONITORING WELL
- ⊕ EXISTING DUAL EXTRACTION WELL
- ⊗ EXISTING VAPOR EXTRACTION WELL
- ▲ EXISTING AIR SPARGE WELL
- () WELL SCREEN BELOW WATER TABLE
- LONG-TERM MONITORING WELL

NOTES:

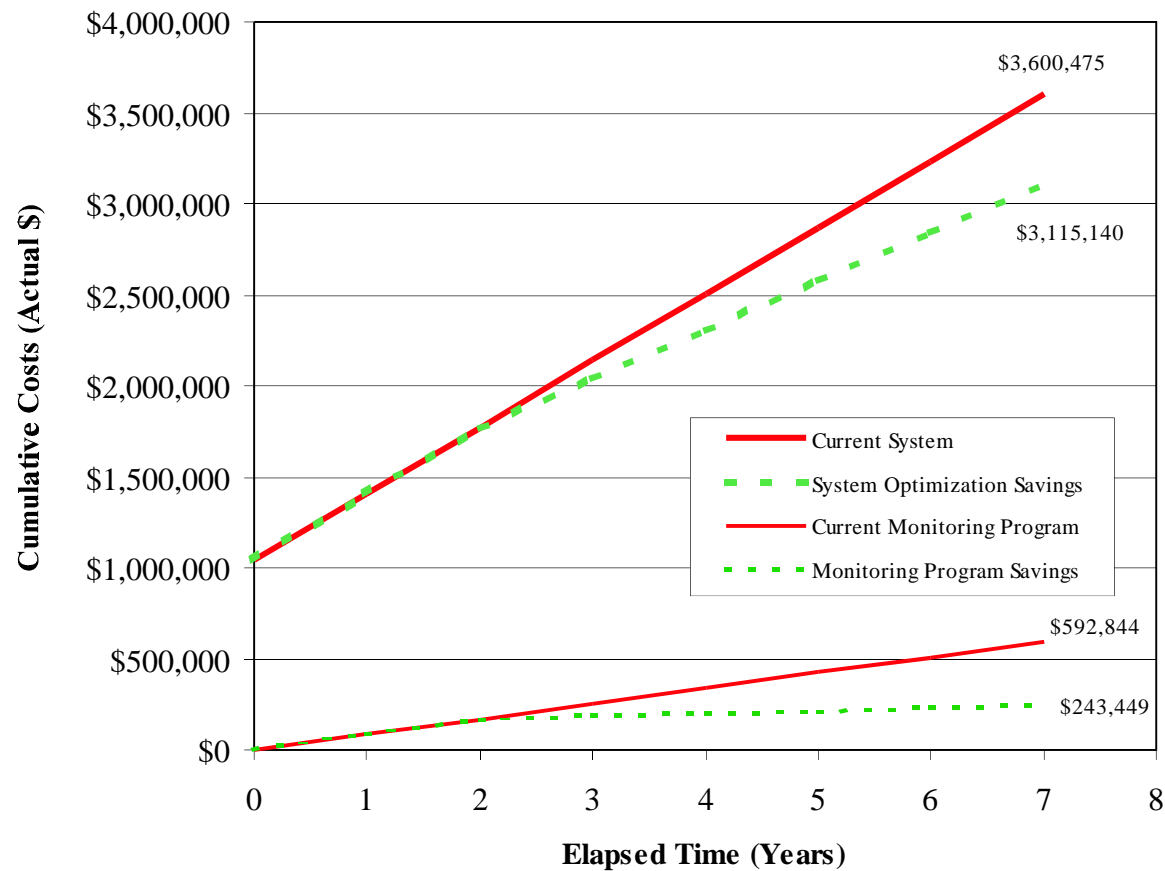
1. ABANDONED WELL 5-MW11 NOT SHOWN.
2. WELLS IN LIGHT SHADE ARE NOT ASSOCIATED WITH THE SITE 5/15 CONTAMINANT PLUME OR ARE NOT BEING MONITORED.



**FIGURE 5.1
RECOMMENDED
SAMPLING LOCATIONS
FOR LONG-TERM
MONITORING WELLS**

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

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**FIGURE 5.2
POTENTIAL
OPTIMIZATION SAVINGS**

Site 5/15 Contaminant Plume
Remedial Process Optimization
Edwards AFB, California

Parsons
parsons engineering science, inc.

Denver, Colorado

dollars at the end of the 7-year period would be approximately \$3.1M or a 13-percent decrease in anticipated costs and a decrease of approximately 27 percent in annual operating expenses. Based on the data, these cost savings will most likely come at no significant impact to the source removal objective.

Monitoring Program

Recommendation No. 4 has the largest overall budgetary impact. Table 5.2 lists the estimated monitoring costs for the recommended sampling program. Reducing the long-term monitoring program by decreasing the sampling frequency, quantity, and number of analytical methods results in estimated cost savings of \$349K over the next five years (Figure 5.2) or \$2.1M (or 82 percent) over a 30 year monitoring period.

5.2 LONG-TERM OPPORTUNITIES

The RPO evaluation has identified several longer-term optimization opportunities that the Air Force should consider. These include both regulatory approaches to establishing realistic clean-up objectives for the site (Section 3) and technical approaches, which could be implemented as alternative ways to manage site remediation.

The following long-term opportunities for remedial system optimization have been identified:

Regulatory

Opportunity No. 1: Proceed with Technical Impracticability Waiver

Impact: There are provisions in both federal and state regulations to apply for an exception to the application of MCLs as an ARAR. In making exceptions for water use designation, the LWQB Basin Plan considers the criteria in the Regional Board Resolution No. 6-89-94. These criteria include conditions for a site where “there is contamination that cannot reasonably be treated for domestic use either by best management practices or best economically achievable practices.” Under the current regulatory framework Site 5/15 appears to meet such criteria. Non-attainability of MCLs in groundwater could be demonstrated under EPA’s TI waiver protocol (see Section 6.1). If the TI waiver was granted for the source area, savings of \$365K annually could be realized immediately by terminating operation of the Site 5/15 source reduction system.

Opportunity No. 2: Establish Site-Specific Clean-Up Goals

Impact: Current conditions at Site 5/15 suggest that re-evaluation of cleanup goals for the site may be appropriate because the MCLs and TDLs proposed as a baseline in the EE/CA may be technically infeasible to achieve (as described in Section 4). Therefore, it is recommended that the Air Force apply for exceptions to the MCLs as cleanup goals for groundwater, which would also affect cleanup goals for soil. Section 3.4 identified one possible approach for establishing risk-based cleanup goals based on industrial land use. At this juncture, the cost impact of implementing this opportunity is difficult to estimate.

TABLE 5.2
COST ESTIMATE FOR RECOMMENDED GROUNDWATER MONITORING PROGRAM^{a/}
SITE 5/15 CONTAMINANT PLUME
REMEDIAL PROCESS OPTIMIZATION
EDWARDS AIR FORCE BASE, CALIFORNIA

Cost type	Quantity	Units	Unit Cost		Cost
Labor for sample collection					
3 people for 5 days at \$60/hr	120	hours	\$	60.00	\$ 7,200.00
Labor for data validation and data management					
2 people for 2 days at \$60/hr	32	hours	\$	60.00	\$ 1,920.00
Laboratory Analyses					
VOCs by Method SW8260	16	samples	\$	120.00	\$ 1,920.00
Ethylene Dibromide by Method E504.1	16	samples	\$	78.00	\$ 1,248.00
Other Direct Costs					
Equipment rental (PID, pH/Eh, O2/CO2, etc.)	5	days	\$	400.00	\$ 2,000.00
Vehicle Rental (2 vehicles for 5 days)	10	days	\$	45.00	\$ 450.00
Miscellaneous Field Supplies					\$ 75.00
SUBTOTAL COST				\$	14,813.00
Long-Term Monitoring for 30 years of annual sampling					x30
TOTAL COST				\$	444,390.00

^{a/} Estimate by Parsons ES.

Technical Approach

Opportunity No. 3: Enhanced TCE Biodegradation

Impact: Continual migration of the TCE contaminant plume beyond the current extent is undesirable. That is why the groundwater recovery system at Site 14 (see Section 1.3.5.4) was installed. The natural migration of the TCE plume is being driven by the subsurface conditions in the underlying groundwater, which are currently unfavorable to TCE degradation (see Section 2.3.2). Based on these subsurface conditions, it appears feasible to enhance the reductive dechlorination of TCE with the addition of an organic substrate such as lactate or vegetable oil. This technology application could be demonstrated on the downgradient portion of the TCE plume. Injecting an organic substrate upgradient of the Site 14 recovery system will allow an assessment to be made of its effectiveness over time within the existing containment system. If it can be demonstrated that organic substrate addition effectively degrades TCE to innocuous by-products, the Site 14 remediation system could eventually be eliminated. Assuming annual operating costs of \$125K, this opportunity could save over \$3.75M (in actual dollars) over a 30-year operational period.

Opportunity No. 4: Bioslurping Technology Implementation

Impact: One course of options the Base is evaluating regarding optimization of the source remediation system is improving the existing liquid recovery system (namely LNAPL recovery) through alternative techniques (e.g., air sparging). Given the heterogeneous nature of the shallow aquifer material, the uniformity and efficiency of air sparging treatment is doubtful. If a long-term operation is being considered for the IRA system (beyond the current 7-year schedule), it would be prudent for the Base to consider re-tooling the system to operate in a “bioslurping” mode. Based on data provided in Engineering Evaluation and Cost Analysis for Bioslurper Initiative (Battelle, 1997), OM&M costs for a conventional bioslurping system are estimated to be approximately 60-percent of the current system at Site 5/15. Over the long-term (10 to 30 years), this O&M savings would off-set any capital investment required by the Base without sacrificing efficiency (Table 4.3) and save \$1.5M to \$4.4M in operating costs.

SECTION 6

IMPLEMENTATION PLAN

6.1 SHORT-TERM RECOMMENDATIONS

As part of this AFCEE RPO initiative, a short-term implementation (9-months) of the recommendations made in Section 5 should be considered and implemented by the Base and their contractors. After the the implementation period, an evaluation of the recommendation effectiveness will be made as part of this demonstration via interviews with Edwards AFB and summarized in a letter report. These events can be implemented based on the following schedule:

Item	Timeframe	Anticipated Schedule
Implementation of recommendations	Subsequent Air Force Consensus	February 2000 - February 2001
Base interview	1-year after implementation of recommendations	March 2001
Letter report submittal	1-month after interview	April 2001

Based on a review of the data collection and reporting efforts to date, it appears that the short-term recommendations made in Section 5.1 can be implemented by the Base contractor with minimal effort. By implementing the changes during regular site visits and maintaining the same level of effort for data collection and reporting, an evaluation of the proposed changes can be made which are consistent with current data collection and reporting techniques. The following is a summary of what is required for implementation:

Recommendation No. 1: Temporarily (approximately 9 months) discontinue the liquid recovery system.

- Prior to termination of the liquid recovery system, collect a round of groundwater elevations in each extraction well.
- At the appropriate time, terminate liquid recovery system operation.
- Prepare system for 6-months of shut-down.

Recommendation No. 2: Temporarily (3-months) reduce the flow-rate and vacuum at each active extraction well (3-months after implementation of Recommendation No. 1).

- Concurrent with the termination of the liquid recovery system, reduce the flow-rate and vacuum at each active extraction well by 20 to 50 percent.
- Monitor system as detailed in the operation and maintenance manual (Earth Tech, 1997) for the next three months with one exception. Perform bimonthly monitoring of the influent vapor stream (USEPA TO-14) as opposed to quarterly monitoring.

Recommendation No. 3: Temporarily (3-months) cycle between extraction wells (3-months after implementation of Recommendation No. 2).

- Maintain flow-rate and vacuum established during implementation of Recommendation No. 2 and cycle between the currently operational vapor extraction wells. Cycle half the wells for a 2-week period and then cycle the other half of the wells for a 2-week period. Continue cycling for the remainder of the implementation schedule.
- Monitor system as detailed in the operation and maintenance manual (Earth Tech, 1997) for the next three months with one exception. Perform bimonthly monitoring of the influent vapor stream (USEPA TO-14) as opposed to quarterly monitoring.

Recommendation No. 4: Reduce the frequency of sampling from semiannual to annual, and reduce the number of wells sampled for the long-term media-monitoring from 56 to 16. In addition, the analyses for gasoline and diesel range hydrocarbons are not necessary and should be dropped.

Results of the 9-month trial period should be reported by the Base contractor in the quarterly operation and maintenance reports. This will maintain consistency for data reduction. An assessment of the trial period's effectiveness will be presented in a letter report following implementation as part of this demonstration.

6.2 LONG-TERM OPPORTUNITIES

It is recommended that the Air Force apply for exceptions to the MCLs and TDLs as cleanup goals for groundwater and soil because these cleanup goals for the primary chemicals of concern (benzene and TCE) may be technically infeasible to achieve. Non-attainability of MCLs in groundwater could be demonstrated using guidance in the LWQB basin plan, Cal EPA regulations (CCR, 1999) and EPA's TI waiver protocol (EPA, 1993). As an alternative to MCLs and TDLs the request for exception should recommend that the risk-based corrective action process be initiated to develop site-specific cleanup goals. This strategy would be most effective under the source area where free product exists. The Air Force should begin discussions with state and federal regulatory agencies as soon as possible because the process of obtaining a TI waiver may take a year or longer.

The following information, identified as part of the RPO, is required to achieve a TI waiver based on EPA's and Cal EPA's criteria (Section 3.4):

- The spatial area for which the TI waiver applies should include the benzene and TCE plumes (Section 2);
- The conceptual site model for the TI waiver (Section 2);
- An analysis of performance of the ongoing remedial action demonstrates that achievement of MCLs in groundwater for benzene and TCE at Site 5/15 is technically impractical from an engineering perspective (Section 4);
- The physical and chemical characteristics of the waste at the site;
- The hydrogeological characteristics of the facility and surrounding land;
- The volume of contaminated groundwater and the direction of groundwater flow;
- The current and potential future uses of groundwater in the area;
- The existing quality of groundwater, including other sources of contamination or pollution and their cumulative impact on the groundwater quality; and
- The persistence and permanence of the potential adverse effects.

In addition to the above noted information, the following may also be required to achieve a TI waiver:

- The proximity and withdrawal rates of groundwater users;
- The potential for health risks caused by human exposure to waste constituents;
- The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;
- The persistence and permanence of the potential adverse effects;
- Alternate media cleanup goals;
- A demonstration that no other remedial technologies (conventional or innovative) could reliably logically or feasibly attain the cleanup levels at the site within a reasonable timeframe; and
- A predictive analysis of timeframe and cost of remediation of groundwater to the alternate media cleanup goals using the existing or proposed remedy options, including construction, operation, and maintenance costs.

The two long-term opportunities identified regarding the technical approach should be applied on a pilot-scale prior to proceeding full-scale. Organic substrate addition could be implemented on the downgradient portion of the Site 5/15 plume upgradient of Site 14. AFCEE/ERT is currently sponsoring a project that will test organic substrate addition at

several test sites. The results of the organic substrate addition should be monitored to assess changes in subsurface geochemistry and lines of evidence of TCE degradation. If successful, the Site 14 recovery system could be terminated and organic substrate addition could be used in the source area. Bioslurping technology could be pilot tested on existing DEWs and moved to full-scale if applicable.

SECTION 7

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PLATE 1

ESTIMATED AREAL EXTENT OF VOLATILE ORGANIC CONTAMINATION SITE 5/15 CONTAMINANT PLUME

Plate 1 is available upon request from Parsons Engineering Science, Inc.

APPENDIX A

RISK-BASED CLEANUP LEVELS

APPENDIX A

RISK-BASED CLEANUP LEVELS

Groundwater (GW) risk-based concentrations (RBCs) and soil-to-GW RBCs have been derived for benzene, ethylene dibromide (EDB), and trichloroethene (TCE) based on an industrial groundskeeper dermal exposure scenario. For information purposed only, these RBCs (dermal exposure scenario) are compared with RBCs based on industrial-based drinking water (DW) RBCs and federal DW maximum contaminant levels (MCLs).

The dermal-based GW RBCs were calculated using the methodology described in USEPA's 1996 *Dermal Exposure Assessment: Principles and Applications* (EPA/600/8-91/011B) and the following assumptions:

- A groundskeeper may be dermally exposed to contaminants in groundwater while watering the grounds (e.g., lawn, flowerbeds, etc.);
- The dermal contact exposure route is the only significant, completed exposure route for the groundskeeper;
- An onsite well will be used to supply the water used by the groundskeeper;
- A groundskeeper may wear a short-sleeved shirt, shorts, and shoes while watering. Therefore, the hands, forearms, and lowerlegs will be the body-parts dermally exposed;
- The groundskeeper will water up to one time per week (assuming a two-week vacation per year), with one event per day and dermal contact occurring for 0.5 hour per event; and
- Dermal-based GW RBC calculations were based on a 1 in 1,000,000 (i.e., $1E-06$) risk goal (carcinogenicity is a more sensitive endpoint than noncancer effects).

Soil RBCs protective of migration-to-groundwater were derived using the methodology described in USEPA's 1996 *Soil Screening Guidance: User's Guide* (EPA/540/R-96/018) and *Technical Background Document* (EPA/540/R95/128), hereafter referred to as the USEPA SSL Guidance Document. USEPA-recommended chemical-specific parameters for benzene and TCE, soil-to-leachate default parameters, and the default dilution attenuation factor (DAF) of 20 (assuming a 0.5-acre source) were used in the calculations (refer to the USEPA SSL Guidance Document).

The results of the dermal-based GW RBC calculations are shown in Table 1. Supporting calculations are provided as Attachment 1. As shown in Table 1, RBCs based on potential dermal contact with contaminated GW ranged from 514 $\mu\text{g/L}$ (reasonable maximum exposure; RME) to 5,140 $\mu\text{g/L}$ (central tendency; CT) for benzene, 0.4 $\mu\text{g/L}$ (RME) to 4 $\mu\text{g/L}$ (CT) for EDB, and 1,260 $\mu\text{g/L}$ (RME) to 12,600 $\mu\text{g/L}$ (CT) for TCE.

For comparison purposes, drinking water-based RBCs ranged from 5 to 10 µg/L for benzene and 5 to 26 µg/L for TCE (Table 1).

TABLE 1
GROUNDWATER RBCs

Contaminant	Groundskeeper RBC _{dermal} (µg/L) ^{a/}		RBC _{DW} (µg/L) ^{b/}	
	RME ^{c/}	CT ^{d/}	RME Industrial-Based RBC ^{e/}	Residential-Based MCL
Benzene	514	5,140	10	5
Ethylene Dibromide	0.4	4	0.003	0.05
TCE	1,260	12,600	26	5

^{a/} RBC_{dermal} = risk-based groundwater concentration based on dermal contact with groundwater for a industrial groundskeeper; µg/L = micrograms per liter.

^{b/} RBC_{DW} = risk-based groundwater concentration based on potential ingestion of groundwater.

^{c/} RME = Reasonable maximum exposure.

^{d/} CT = Central tendency exposure.

^{e/} Assumed ingestion of one liter per day, 250 days per year for 25 years.

The results of the migration-to-groundwater soil RBC calculations are shown in Table 2. Supporting calculations are provided in Attachment 1. As shown in Table 2, soil RBCs protective of migration-to-groundwater and potential dermal contact (groundskeeper) with GW ranged from 4 mg/kg (RME) to 34 mg/kg (CT) for benzene, 0.003 mg/kg (RME) to 0.03 mg/kg (CT) for EDB, and 14 mg/kg (RME) to 140 mg/kg (CT) for TCE. For comparison purposes, soil RBCs protective of migration-to-groundwater and potential residential/industrial ingestion ranged from 0.03 to 0.07 mg/kg for benzene and 0.06 to 0.3 mg/kg for TCE.

TABLE 2
MIGRATION-TO-GROUNDWATER SOIL RBCs

Contaminant	Groundskeeper RBC _{soil-to-GW} Based on Dermal Contact with Groundwater (mg/kg) ^{a/}		RBC _{soil-to-GW} Based on Potential Ingestion of Groundwater (mg/kg)	
	RME ^{b/}	CT ^{c/}	RME Industrial-Based	Residential (MCL-based)
Benzene	4	35	0.07	0.03
Ethylene Dibromide	0.003	0.03	0.00002	0.0003
TCE	14	140	0.3	0.06

^{a/} RBC_{soil-to-GW} = risk-based soil concentration protective of potential migration to groundwater; mg/kg = milligrams per kilogram.

^{b/} RME = Reasonable maximum exposure.

^{c/} CT = Central tendency exposure.

APPENDIX C: RISK CALCULATION SHEETS
CHEMICAL PROPERTIES
INDUSTRIAL LAND USE ASSUMPTIONS
REMEDIAL PROCESS OPTIMIZATION REPORT, EDWARDS AIR FORCE BASE

	CAS Number ^{b/}	Type ^{c/}	Chemical Properties ^{a/}															
			t* (hr) ^{d/}	Ref ^{e/}	K _p (cm/hr) ^{f/}	Ref	t _{event} (hr/event) ^{g/}	Ref	B (unitless)	Ref	OAF (unitless)	Ref	Sf _{oral} (mg/kg-day) ⁻¹ h ^{h/}	Ref	SF _d (mg/kg-day) ⁻¹	RfD _{oral} (mg/kg-day)	Ref	RfD _d (mg/kg-day)
Volatile Organic Compounds																		
Benzene	71-43-2	o	6.30E-01	D	2.10E-02	D	2.60E-01	D	1.30E-02	D	0.97	Bast, 1996	2.90E-02	I	2.99E-02	3.00E-03	E	2.91E-03
Ethylene dibromide	106-93-4	o	2.90E+00	D	3.30E-03	D	1.20E+00	D	9.10E-03	D	0.8	USEPA R4, 1995	8.50E+01	I	1.06E+02	5.70E-05	X	4.56E-05
Trichloroethene	79-01-6	o	1.30E+00	D	1.60E-02	D	5.50E-01	D	2.60E-02	D	1	Lee, 1997, Green, 1985, & Dekant, 1986	1.10E-02	W	1.10E-02	6.00E-03	E	6.00E-03

^{a/} Chemical Properties are defined as follows: t* = time it takes to reach steady state, K_p = Permeability coefficient from water, t_{event} = lag time per event, B = Relative contribution of permeability coefficients,

OAF = oral absorption factor, SF_{oral} = oral slope factor, SF_d = dermal slope factor (i.e., oral slope factor adjusted for gastrointestinal absorption), RfD_{oral} = oral reference dose, RfD_d = dermal reference dose (i.e., oral reference dose adjusted for gastrointestinal absorption),

^{b/} CAS = Chemical Abstracts Service number.

^{c/} "o" indicates an organic compound, "i" indicates an inorganic compound

^{d/} hr = hour

^{e/} Ref = References as defined below.

^{f/} cm/hr = centimeters per hour

^{g/} hr/event = hours per event

^{h/} mg/kg-day = milligrams per kilogram-day

References:

D = USEPA (1992) *Dermal Exposure Assessment: Principles and Applications*. EPA/600/7-91/011B.

I = USEPA (1999), *Integrated Risk Information System (IRIS)*.

E = USEPA National Center for Environmental Assessment per USEPA Region 3 (1998). *Risk-Based Concentration Table*. October 1, 1998

W = Withdrawn from IRIS or HEAST.

X = Based on route-to-route extrapolation per USEPA Region IX (1998) PRG Table.

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CALCULATION OF SCREENING LEVEL PRELIMINARY REMEDIATION GOALS - GROUNDWATER ^{a/}
INDUSTRIAL LAND USE - RME SCENARIO
RSA REPORT

Exposure Assumptions		DA _{event} Equations
Receptor	Groundskeeper: RME Scenario	Carcinogenic:
Dose absorbed per unit area per event (DA _{event})	chemical-specific mg/cm ² -event ^{a/}	$DA_{event_{carc}} = \frac{(TR)(BW)(AT_c)(365day/year)}{(SF_d)(EF)(ED)(EV)(EC)(SA)}$
Target cancer risk level (TR)	1.00E-06 unitless	
Body Weight (BW)	70 kg	
Averaging Time, Carcinogens (AT _c)	70 yrs	
Dermal Slope Factor (SF _d) (i.e., SF _o adjusted for GI absorption)	chemical-specific (mg/kg-day) ⁻¹ ^{b/}	where $SF_d = \frac{(SF_o)}{(OAF)}$ and: OAF = Oral GI absorption factor (chemical-specific; unitless)
Exposure Frequency (EF)	50 days/yr ^{c/}	Noncarcinogenic:
Exposure Duration (ED)	25 yr	
Event Frequency (EV)	1 events/day	
Fraction of Estimated Time in Contact with Water (EC)	1 unitless	
Exposed Body Surface Area (SA)	4450 cm ²	$DA_{event_{nc}} = \frac{(THQ)(BW)(RfD_d)(AT_{nc})(365day/year)}{(EF)(ED)(EV)(EC)(SA)}$
Target hazard quotient (THQ)	1 unitless	
Dermal Reference Dose (RfD _d) (i.e., RfD _o adjusted for GI absorption)	chemical-specific mg/kg-day	
Averaging Time, Noncarcinogens (AT _{nc})	25 yr	
		where $RfD_d = (RfD_o)(OAF)$

Contaminant	CAS Number ^{d/}	SF _o (mg/kg-day) ⁻¹	RfD _o (mg/kg-day)	OAF (unitless)	SF _d (mg/kg-day) ⁻¹	RfD _d (mg/kg-day)	DA _{event_{carc}} (mg/cm ² -event)	DA _{event_{nc}} (mg/cm ² -event)	DA _{event} (mg/cm ² -event)	COPC Classification for DA _{event} ^{d/}
Volatile Organic Compounds										
Benzene	71-43-2	2.90E-02	3.00E-03	9.70E-01	2.99E-02	2.91E-03	1.08E-05	3.34E-04	1.08E-05	C
Ethylene dibromide	106-93-4	8.50E+01	5.70E-05	8.00E-01	1.06E+02	4.56E-05	3.03E-09	5.24E-06	3.03E-09	C
Trichloroethene	79-01-6	1.10E-02	6.00E-03	1.00E+00	1.10E-02	6.00E-03	2.92E-05	6.89E-04	2.92E-05	C

^{a/} mg/cm² = milligram per square centimeter.

^{b/} mg/kg-day = milligram per kilogram-day

^{c/} days/yr = days per year

^{d/} CAS = Chemical Abstracts Service number.

^{e/} -- = toxicity data not available.

CALCULATION OF SCREENING LEVEL PRELIMINARY REMEDIATION GOALS - GROUNDWATER ^{a/}
INDUSTRIAL LAND USE - CT SCENARIO
RSA REPORT

Input Parameters			PRG Equations	
Receptor	Groundskeeper: CT Scenario		For inorganics:	
Site-specific preliminary remediation goal based on dermal contact with groundwater (PRG _{derm})	chemical-specific	µg/L ^{a/}	$PRG_{derm-inorg} = \frac{(DA_{event})(CF)}{(K_p)(t_{event})}$	
Dose absorbed per unit area per event (DA _{event})	chemical-specific	mg/cm ² -event ^{b/}		
Conversion Factor (CF)	1.00E+06	(ml/L) x (µg/mg) ^{c/}	For organics:	
Permeability coefficient from water (K _p)	Chemical-specific	cm/hr ^{d/}		
Duration of event (t _{event})	0.5	hr/event ^{e/}	If t _{event} < t*, then: $PRG_{derm-org} = \frac{(DA_{event})(CF)}{2K_p \sqrt{\frac{6t_{event} t_{event}}{p}}}$	
Time it takes to reach steady state (t*)	Chemical-specific	hr/event		
Lag time per event (t _{event})	Chemical-specific	hr/event	If t _{event} > t*, then: $PRG_{derm-org} = \frac{(DA_{event})(CF)}{K_p \left[\frac{t_{event}}{1+B} + 2t_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]}$	
Relative contribution of permeability coefficients in stratum corneum and viable epidermis (B)	Chemical-specific	unitless		

Contaminant	Type ^{f/}	K _p (cm/hr)	t* (hr/event)	t _{event} (hr/event)	B (unitless)	DA _{event} (mg/cm ² -event)	PRG _{derm-c} (µg/L)	PRG _{derm-nc} (µg/L)	PRG _{derm} (µg/L)	COPC Classification for PRG _{derm} ^{d/}
Volatile Organic Compounds										
Benzene	o	2.10E-02	6.30E-01	2.60E-01	1.30E-02	1.08E-04		5.14E+03	5.14E+03	C
Ethylene dibromide	o	3.30E-03	2.90E+00	1.20E+00	9.10E-03	3.03E-08		4.28E+00	4.28E+00	C
Trichloroethene	o	1.60E-02	1.30E+00	5.50E-01	2.60E-02	2.92E-04		1.26E+04	1.26E+04	C

^{a/} µg/L = micrograms per liter

^{b/} mg/cm²-event = milligrams per centimeter-event

^{c/} (ml/L) x (µg/mg) = milliliter per liter times microgram per milligram

^{d/} cm/hr = centimeters per hour

^{e/} hr/event = hours per event

^{f/} "o" indicates an organic compound, "i" indicates an inorganic compound

CALCULATION OF SCREENING LEVEL PRELIMINARY REMEDIATION GOALS - GROUNDWATER ^{a/}
INDUSTRIAL LAND USE - RME SCENARIO
RSA REPORT

Input Parameters			PRG Equations	
Receptor	Groundskeeper: RME Scenario		For inorganics:	
Site-specific preliminary remediation goal based on dermal contact with groundwater (PRG _{derm})	chemical-specific	µg/L ^{a/}	$PRG_{derm-inorg} = \frac{(DA_{event})(CF)}{(K_p)(t_{event})}$	
Dose absorbed per unit area per event (DA _{event})	chemical-specific	mg/cm ² -event ^{b/}		
Conversion Factor (CF)	1.00E+06	(ml/L) x (µg/mg) ^{c/}	For organics:	
Permeability coefficient from water (K _p)	Chemical-specific	cm/hr ^{d/}		
Duration of event (t _{event})	0.5	hr/event ^{e/}	If t _{event} < t*, then: $PRG_{derm-org} = \frac{(DA_{event})(CF)}{2K_p \sqrt{\frac{6t_{event} t_{event}}{p}}}$	
Time it takes to reach steady state (t*)	Chemical-specific	hr/event		
Lag time per event (t _{event})	Chemical-specific	hr/event	If t _{event} > t*, then: $PRG_{derm-org} = \frac{(DA_{event})(CF)}{K_p \left[\frac{t_{event}}{1+B} + 2t_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]}$	
Relative contribution of permeability coefficients in stratum corneum and viable epidermis (B)	Chemical-specific	unitless		

Contaminant	Type ^{f/}	K _p (cm/hr)	t* (hr/event)	t _{event} (hr/event)	B (unitless)	DA _{event} (mg/cm ² -event)	PRG _{derm-inorg} (µg/L)	PRG _{derm-organic} (µg/L)	PRG _{derm} (µg/L)	COPC Classification for PRG _{derm} ^{d/}
Volatile Organic Compounds										
Benzene	o	2.10E-02	6.30E-01	2.60E-01	1.30E-02	1.08E-05		5.14E+02	5.14E+02	C
Ethylene dibromide	o	3.30E-03	2.90E+00	1.20E+00	9.10E-03	3.03E-09		4.28E-01	4.28E-01	C
Trichloroethene	o	1.60E-02	1.30E+00	5.50E-01	2.60E-02	2.92E-05		1.26E+03	1.26E+03	C

^{a/} µg/L = micrograms per liter

^{b/} mg/cm²-event = milligrams per centimeter-event

^{c/} (ml/L) x (µg/mg) = milliliter per liter times microgram per milligram

^{d/} cm/hr = centimeters per hour

^{e/} hr/event = hours per event

^{f/} "o" indicates an organic compound, "i" indicates an inorganic compound

CALCULATION OF SCREENING LEVEL PRELIMINARY REMEDIATION GOALS - GROUNDWATER ^{a/}
INDUSTRIAL LAND USE - CT SCENARIO
RSA REPORT

Exposure Assumptions		DA _{event} Equations
Receptor	Groundskeeper: CT Scenario	Carcinogenic:
Dose absorbed per unit area per event (DA _{event})	chemical-specific mg/cm ² -event ^{a/}	$DA_{event\,carc} = \frac{(TR)(BW)(AT_c)(365day/year)}{(SF_d)(EF)(ED)(EV)(EC)(SA)}$
Target cancer risk level (TR)	1.00E-06 unitless	
Body Weight (BW)	70 kg	
Averaging Time, Carcinogens (AT _c)	70 yrs	
Dermal Slope Factor (SF _d) (i.e., SF _o adjusted for GI absorption)	chemical-specific (mg/kg-day) ⁻¹ ^{b/}	where $SF_d = \frac{(SF_o)}{(OAF)}$ and: OAF = Oral GI absorption factor (chemical-specific; unitless)
Exposure Frequency (EF)	25 days/yr ^{c/}	Noncarcinogenic:
Exposure Duration (ED)	5 yr	
Event Frequency (EV)	1 events/day	
Fraction of Estimated Time in Contact with Water (EC)	1 unitless	
Exposed Body Surface Area (SA)	4450 cm ²	$DA_{event\,nc} = \frac{(THQ)(BW)(RfD_d)(AT_{nc})(365day/year)}{(EF)(ED)(EV)(EC)(SA)}$
Target hazard quotient (THQ)	1 unitless	
Dermal Reference Dose (RfD _d) (i.e., RfD _o adjusted for GI absorption)	chemical-specific mg/kg-day	
Averaging Time, Noncarcinogens (AT _{nc})	5 yr	
		where $RfD_d = (RfD_o)(OAF)$

Contaminant	CAS Number ^{d/}	SF _o (mg/kg-day) ⁻¹	RfD _o (mg/kg-day)	OAF (unitless)	SF _d (mg/kg-day) ⁻¹	RfD _d (mg/kg-day)	DA _{event} _{carc} (mg/cm ² -event)	DA _{event} _{nc} (mg/cm ² -event)	DA _{event} (mg/cm ² -event)	COPC Classification for DA _{event} ^{d/}
Volatile Organic Compounds										
Benzene	71-43-2	2.90E-02	3.00E-03	9.70E-01	2.99E-02	2.91E-03	1.08E-04	6.68E-04	1.08E-04	C
Ethylene dibromide	106-93-4	8.50E+01	5.70E-05	8.00E-01	1.06E+02	4.56E-05	3.03E-08	1.05E-05	3.03E-08	C
Trichloroethene	79-01-6	1.10E-02	6.00E-03	1.00E+00	1.10E-02	6.00E-03	2.92E-04	1.38E-03	2.92E-04	C

^{a/} mg/cm² = milligram per square centimeter.

^{b/} mg/kg-day = milligram per kilogram-day

^{c/} days/yr = days per year

^{d/} CAS = Chemical Abstracts Service number.

^{e/} -- = toxicity data not available.

CALCULATION OF SCREENING LEVEL PRELIMINARY REMEDIATION GOALS - GROUNDWATER ^{a/}
INDUSTRIAL LAND USE - RME SCENARIO
RSA REPORT

Exposure Assumptions		PRG Equations
Receptor	Groundskeeper: RME Scenario	Carcinogenic:
Site-specific preliminary remediation goal based on incidental ingestion of groundwater (PRG _{ing})	chemical-specific µg/L ^{a/}	$PRG_{ing-c} = \frac{(TR)(BW)(AT_c)(365day/year)}{(SF_o)(IR_w)(EF)(ED)(CF)}$
Target cancer risk level (TR)	1.00E-06 unitless	
Body Weight (BW)	70 kg	
Averaging Time, Carcinogens (AT _c)	70 yrs	<p>Noncarcinogenic:</p> $PRG_{ing-nc} = \frac{(THQ)(BW)(RfD_o)(AT_{nc})(365day/year)}{(IR_w)(EF)(ED)(CF)}$
Oral Slope Factor (SF _o)	chemical-specific (mg/kg-day) ⁻¹ ^{b/}	
Water Ingestion Rate (IR _w)	1 L/day	
Exposure Frequency (EF)	250 days/yr	
Exposure Duration (ED)	25 yr	
Conversion Factor (CF)	0.001 mg/µg	
Target hazard quotient (THQ)	1 unitless	
Oral Reference Dose (RfD _o)	chemical-specific mg/kg-day	
Averaging Time, Noncarcinogens (AT _{nc})	25 yr	

Contaminant	CAS Number ^{c/}	SF _o (mg/kg-day) ⁻¹	RfD _o (mg/kg-day)	PRG _{ing-c} (µg/L)	PRG _{ing-nc} (µg/L)	PRG _{ing} (µg/L)	COPC Classification for PRG _{ing} ^{d/}
Volatile Organic Compounds							
Benzene	71-43-2	2.90E-02	3.00E-03	9.87E+00	3.07E+02	9.87E+00	C
Ethylene dibromide	106-93-4	8.50E+01	5.70E-05	3.37E-03	5.83E+00	3.37E-03	C
Trichloroethene	79-01-6	1.10E-02	6.00E-03	2.60E+01	6.13E+02	2.60E+01	C

^{a/} µg/L = microgram per liter

^{b/} mg/kg-day = milligram per kilogram-day

^{c/} CAS = Chemical Abstracts Service number.

^{d/} -- = toxicity data not available.

CALCULATIONS FOR ESTIMATING SOIL-TO-GROUNDWATER SCREENING LEVELS ^{a/}
GROUNDWATER SCREENING VALUE BASED ON DERMAL CONTACT (RME SCENARIO)
SITE-SPECIFIC RSA REPORT

Equations	Input Parameters	Definition	Input Parameters
$RBC_{soil-GW} = C_w [K_d + ((q_w + q_a * H')/r_b)]$	$RBC_{soil-GW}$	Risk-based concentration in soil based on soil-to-groundwater migration (mg/kg) ^{b/}	chemical-specific
	C_w	Target soil leachate concentration (mg/L) ^{c/}	chemical-specific
	DAF	Dilution-Attenuation Factor	2.0E+01
where:	K_{oc}	Soil organic carbon partition coefficient (L/kg) ^{d/}	chemical-specific
$C_w = \text{groundwater screening value} \times \text{DAF}$	K_d	Soil-water partition coefficient (L/kg)	chemical-specific
$K_d = K_{oc} * f_{oc}$	f_{oc}	Fraction organic carbon content in soil (kg/kg) ^{e/}	2.0E-03
$\log K_{oc} = 0.0784 + (0.7919 * \log K_{ow})$	q_w	Water filled soil porosity (L_{water}/L_{soil}) ^{f/}	3.0E-01
	q_a	Air filled soil porosity (L_{air}/L_{soil}) ^{g/}	1.3E-01
	r_b	Dry soil bulk density (kg/L) ^{h/}	1.5E+00
	H'	Henry's law constant (dimensionless)	chemical-specific
	$\log K_{ow}$	Octanol/water partition coefficient	chemical-specific

Chemical	Groundwater Screening Value (µg/L)	Groundwater Screening Value (mg/L)	C_w	$\log K_{ow}$	$\log K_{oc}$	K_{oc}	K_d	H'	$RBC_{soil-GW}$
Organics									
Benzene	5.14E+02	5.14E-01	1.03E+01	2.13E+00	1.77E+00	5.82E+01	1.16E-01	2.28E-01	3.5E+00
Ethylene dibromide	4.28E-01	4.28E-04	8.56E-03	1.96E+00	1.63E+00	4.27E+01	8.54E-02	3.22E-02	2.5E-03
Trichloroethene	1.26E+03	1.26E+00	2.52E+01	2.71E+00	2.22E+00	1.68E+02	3.35E-01	4.22E-01	1.4E+01

^{a/} Calculations were done per 1996 USEPA *Soil Screening Guidance: Technical Background Document* (EPA/540/R95/128)

^{b/} mg/kg = milligrams per kilogram

^{c/} mg/L = milligrams per liter

^{d/} L/kg = liters per kilogram

^{e/} kg/kg = kilogram per kilogram

^{f/} L_{water}/L_{soil} = liters of water per liters of soil

^{g/} L_{air}/L_{soil} = liters of air per liters of soil

^{h/} kg/L = kilograms per liter

CALCULATIONS FOR ESTIMATING SOIL-TO-GROUNDWATER SCREENING LEVELS ^{a/}
GROUNDWATER SCREENING VALUE BASED ON DERMAL CONTACT (CT SCENARIO)
SITE-SPECIFIC RSA REPORT

Equations	Input Parameters	Definition	Input Parameters
$RBC_{soil-GW} = C_w [K_d + ((q_w + q_a * H')/r_b)]$	$RBC_{soil-GW}$	Risk-based concentration in soil based on soil-to-groundwater migration (mg/kg) ^{b/}	chemical-specific
	C_w	Target soil leachate concentration (mg/L) ^{c/}	chemical-specific
	DAF	Dilution-Attenuation Factor	2.0E+01
where:	K_{oc}	Soil organic carbon partition coefficient (L/kg) ^{d/}	chemical-specific
$C_w = \text{groundwater screening value} \times \text{DAF}$	K_d	Soil-water partition coefficient (L/kg)	chemical-specific
$K_d = K_{oc} * f_{oc}$	f_{oc}	Fraction organic carbon content in soil (kg/kg) ^{e/}	2.0E-03
$\log K_{oc} = 0.0784 + (0.7919 * \log K_{ow})$	q_w	Water filled soil porosity (L_{water}/L_{soil}) ^{f/}	3.0E-01
	q_a	Air filled soil porosity (L_{air}/L_{soil}) ^{g/}	1.3E-01
	r_b	Dry soil bulk density (kg/L) ^{h/}	1.5E+00
	H'	Henry's law constant (dimensionless)	chemical-specific
	$\log K_{ow}$	Octanol/water partition coefficient	chemical-specific

Chemical	Groundwater Screening Value (µg/L)	Groundwater Screening Value (mg/L)	C_w	$\log K_{ow}$	$\log K_{oc}$	K_{oc}	K_d	H'	$RBC_{soil-GW}$
Organics									
Benzene	5.14E+03	5.14E+00	1.03E+02	2.13E+00	1.77E+00	5.82E+01	1.16E-01	2.28E-01	3.5E+01
Ethylene dibromide	4.28E+00	4.28E-03	8.56E-02	1.96E+00	1.63E+00	4.27E+01	8.54E-02	3.22E-02	2.5E-02
Trichloroethene	1.26E+04	1.26E+01	2.52E+02	2.71E+00	2.22E+00	1.68E+02	3.35E-01	4.22E-01	1.4E+02

^{a/} Calculations were done per 1996 USEPA *Soil Screening Guidance: Technical Background Document* (EPA/540/R95/128)

^{b/} mg/kg = milligrams per kilogram

^{c/} mg/L = milligrams per liter

^{d/} L/kg = liters per kilogram

^{e/} kg/kg = kilogram per kilogram

^{f/} L_{water}/L_{soil} = liters of water per liters of soil

^{g/} L_{air}/L_{soil} = liters of air per liters of soil

^{h/} kg/L = kilograms per liter

CALCULATIONS FOR ESTIMATING SOIL-TO-GROUNDWATER SCREENING LEVELS^{a/}
GROUNDWATER SCREENING VALUE BASED ON RME INDUSTRIAL DRINKING WATER RBCs
SITE-SPECIFIC RSA REPORT

Equations	Input Parameters	Definition	Input Parameters
$RBC_{soil-GW} = C_w [K_d + ((q_w + q_a * H')/r_b)]$	$RBC_{soil-GW}$	Risk-based concentration in soil based on soil-to-groundwater migration (mg/kg) ^{b/}	chemical-specific
	C_w	Target soil leachate concentration (mg/L) ^{c/}	chemical-specific
	DAF	Dilution-Attenuation Factor	2.0E+01
where:	K_{oc}	Soil organic carbon partition coefficient (L/kg) ^{d/}	chemical-specific
$C_w = \text{groundwater screening value} \times \text{DAF}$	K_d	Soil-water partition coefficient (L/kg)	chemical-specific
$K_d = K_{oc} * f_{oc}$	f_{oc}	Fraction organic carbon content in soil (kg/kg) ^{e/}	2.0E-03
$\log K_{oc} = 0.0784 + (0.7919 * \log K_{ow})$	q_w	Water filled soil porosity (L_{water}/L_{soil}) ^{f/}	3.0E-01
	q_a	Air filled soil porosity (L_{air}/L_{soil}) ^{g/}	1.3E-01
	r_b	Dry soil bulk density (kg/L) ^{h/}	1.5E+00
	H'	Henry's law constant (dimensionless)	chemical-specific
	$\log K_{ow}$	Octanol/water partition coefficient	chemical-specific

Chemical	Groundwater Screening Value (µg/L)	Groundwater Screening Value (mg/L)	C_w	$\log K_{ow}$	$\log K_{oc}$	K_{oc}	K_d	H'	$RBC_{soil-GW}$
Organics									
Benzene	1.00E+01	1.00E-02	2.00E-01	2.13E+00	1.77E+00	5.82E+01	1.16E-01	2.28E-01	6.7E-02
Ethylene dibromide	3.40E-03	3.40E-06	6.80E-05	1.96E+00	1.63E+00	4.27E+01	8.54E-02	3.22E-02	2.0E-05
Trichloroethene	2.60E+01	2.60E-02	5.20E-01	2.71E+00	2.22E+00	1.68E+02	3.35E-01	4.22E-01	3.0E-01

^{a/} Calculations were done per 1996 USEPA *Soil Screening Guidance: Technical Background Document* (EPA/540/R95/128)

^{b/} mg/kg = milligrams per kilogram

^{c/} mg/L = milligrams per liter

^{d/} L/kg = liters per kilogram

^{e/} kg/kg = kilogram per kilogram

^{f/} L_{water}/L_{soil} = liters of water per liters of soil

^{g/} L_{air}/L_{soil} = liters of air per liters of soil

^{h/} kg/L = kilograms per liter

CALCULATIONS FOR ESTIMATING SOIL-TO-GROUNDWATER SCREENING LEVELS ^{a/}
GROUNDWATER SCREENING VALUE BASED ON MCLs
SITE-SPECIFIC RSA REPORT

Equations	Input Parameters	Definition	Input Parameters
$RBC_{soil-GW} = C_w [K_d + ((q_w + q_a * H')/r_b)]$	$RBC_{soil-GW}$	Risk-based concentration in soil based on soil-to-groundwater migration (mg/kg) ^{b/}	chemical-specific
	C_w	Target soil leachate concentration (mg/L) ^{c/}	chemical-specific
	DAF	Dilution-Attenuation Factor	2.0E+01
where:	K_{oc}	Soil organic carbon partition coefficient (L/kg) ^{d/}	chemical-specific
$C_w = \text{groundwater screening value} \times \text{DAF}$	K_d	Soil-water partition coefficient (L/kg)	chemical-specific
$K_d = K_{oc} * f_{oc}$	f_{oc}	Fraction organic carbon content in soil (kg/kg) ^{e/}	2.0E-03
$\log K_{oc} = 0.0784 + (0.7919 * \log K_{ow})$	q_w	Water filled soil porosity (L_{water}/L_{soil}) ^{f/}	3.0E-01
	q_a	Air filled soil porosity (L_{air}/L_{soil}) ^{g/}	1.3E-01
	r_b	Dry soil bulk density (kg/L) ^{h/}	1.5E+00
	H'	Henry's law constant (dimensionless)	chemical-specific
	$\log K_{ow}$	Octanol/water partition coefficient	chemical-specific

Chemical	Groundwater Screening Value (µg/L)	Groundwater Screening Value (mg/L)	C_w	$\log K_{ow}$	$\log K_{oc}$	K_{oc}	K_d	H'	$RBC_{soil-GW}$
Organics									
Benzene	5.00E+00	5.00E-03	1.00E-01	2.13E+00	1.77E+00	5.82E+01	1.16E-01	2.28E-01	3.4E-02
Ethylene dibromide	5.00E-02	5.00E-05	1.00E-03	1.96E+00	1.63E+00	4.27E+01	8.54E-02	3.22E-02	2.9E-04
Trichloroethene	5.00E+00	5.00E-03	1.00E-01	2.71E+00	2.22E+00	1.68E+02	3.35E-01	4.22E-01	5.7E-02

^{a/} Calculations were done per 1996 USEPA *Soil Screening Guidance: Technical Background Document* (EPA/540/R95/128)

^{b/} mg/kg = milligrams per kilogram

^{c/} mg/L = milligrams per liter

^{d/} L/kg = liters per kilogram

^{e/} kg/kg = kilogram per kilogram

^{f/} L_{water}/L_{soil} = liters of water per liters of soil

^{g/} L_{air}/L_{soil} = liters of air per liters of soil

^{h/} kg/L = kilograms per liter

APPENDIX B

COST ESTIMATES

Client AFCEE ERT
 Subject RPO-EDWARDS AFB
ESTIMATED COSTS

Job No. 734429
 By WA
 Checked PPY

Sheet 1 of 18
 Date 6.15.99
 Rev. WA

OBS: EST. FROM VARIOUS SOURCES TOTAL CAPITAL
 AND O&M COSTS FOR EDWARDS SITE S/IS;
 EST. COST PER 16 VOC REMOVED TO DATE;
 AND EST. OPTIMIZATION SAVINGS

ESTIMATE:

- 1) COST OF TS WHICH INCLUDED INSTALLATION
 AND 1 YR O&M = \$1,319,475 (ATTACHMENT 1)
 THROUGH APR 1998

• THIS COST DID NOT INCLUDE
 UTILITIES (ELEC & FUEL) SINCE THEY ARE
 NOT METERED, EE/CA ESTIMATES
 WERE \$89,200/YR (ATTACHMENT 2) ∴
 TOTAL COSTS = \$1,319,475 + \$89,200
 = \$1,408,675

- 2) COST OF O&M EST BY BASE = \$276,100 (ATTACHMENT 3)
 DOES NOT INCLUDE UTILITIES = \$89,200

$$\text{TOTAL} = \$365,300$$

- 3) EST TOTAL COSTS THROUGH APR 1999^y
 = \$1,408,675 + \$365,300 $\left(\frac{12}{12}\right)$ = \$1,773,975

APR 1997 - APR 1998

MAY 1998 - APR 1999

- 4) DOES NOT INCLUDE WELL FIELD MONITORING PROGRAM
 DOES NOT INCLUDE AER SPARGING SYSTEM INSTALLED
 IN JAN 1999.

Client AFLE ERT
 Subject RPO - EDWARDS AFB
ESTIMATED COSTS

Job No. 734429
 By NAP
 Checked PPY.

Sheet 2 of 18
 Date 6.15.99
 Rev. 0

- 4) EST OF COST PER POUND VOCs REMOVED THROUGH APR 1999 ASSUMING ALL CAPITAL COSTS (NO PRORATING COSTS); ASSUME 50:50 SPLIT BETWEEN LIQUID AND VAPOR SYSTEM

PHASE	VAPOR	LIQUID (FREE & DISSOLVED)
VOCs (lbs) ^{b/}	350,597	5,171
COST (\$1,773,975) <u>2</u>	\$ 886,988	\$ 886,987
\$/lb VOC	\$2.40	\$ 171.53
\$/lb BENZENE ^{b/} (1,104 lb)	\$ 803.43	—
\$/lb TCE ^w (909 lb)	\$ 976.78	—

^{b/} ATTACHMENT 4: ALL CUMULATIVE lbs REMOVED THROUGH APR 1999 WITH THE EXCEPTION OF VOCs IN VAPOR PHASE (THROUGH JAN 1999) BECAUSE OF QUESTIONABLE ANALYTICAL DATA.

NOTE: DOES NOT INCLUDE COST OF lbs OF VOCs REMOVED BY AIR SPARGING PILOT TEST PERFORMED IN JAN 1999

Client AKEE ERT
Subject RPO-EDWARDS AFB
ESTIMATED COSTS

Job No. 734429
By WAP
Checked WAP

Sheet 3 of 18
Date 6-16-99
Rev. _____

5) ESTIMATE FUTURE O&M SAVINGS w/
OPTIMIZATIONS WHICH INCLUDES

- A. TERMINATING LIQUID SYSTEM
- B. TURN-DOWN SVE BY 20%

▶ SEE ATTACHMENT 5 & 6 FOR ASSUMPTIONS

$$\begin{aligned}\blacktriangleright \text{ NEW YEARLY O\&M COST} &= \cancel{\$}216,600 + \cancel{\$}51,633 \\ &= \boxed{\$268,233}\end{aligned}$$

▶ EST PROGRAM SAVINGS - SEE PG 4 OF 17.

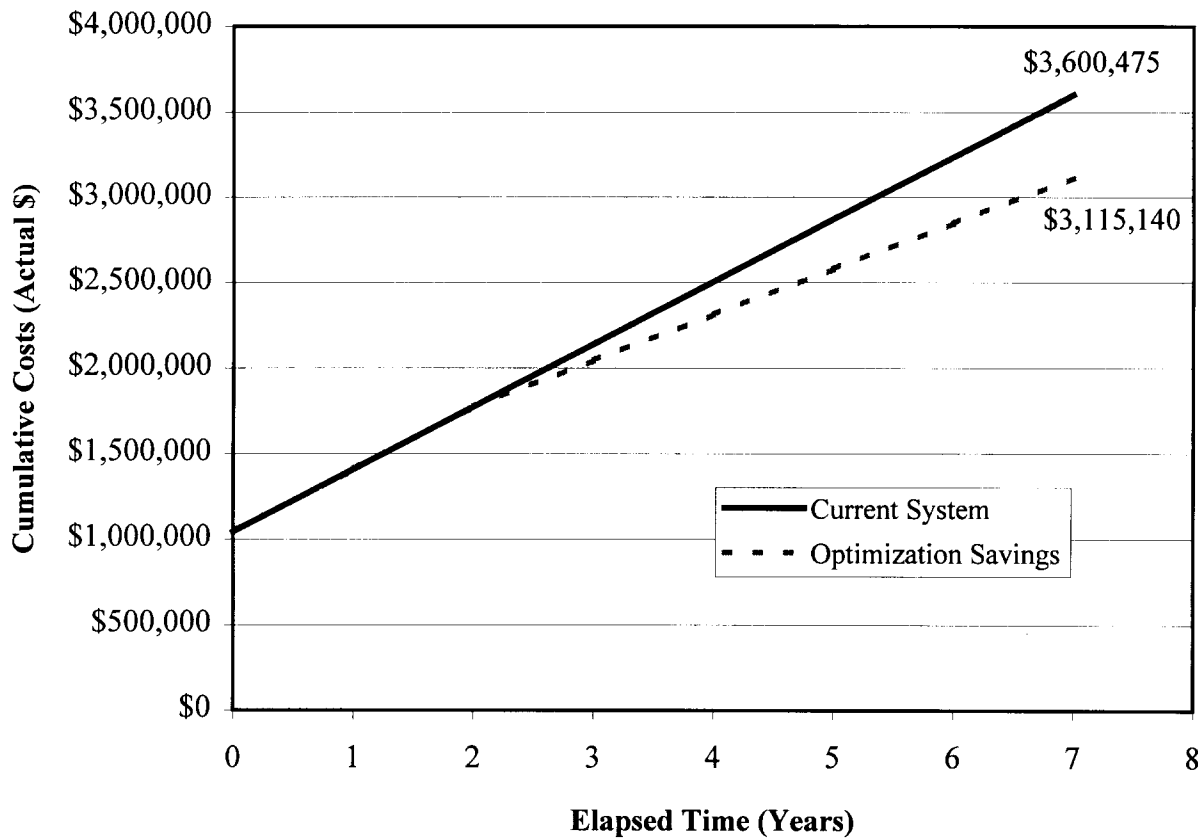
5) CONTINUED

4 of 18

EDWARDS AFB RPO COST SUMMARY

Current System			Optimization Savings					
Year	Cost	Cumulative Cost	Cost	Cumulative Cost	Yearly Difference	Yearly Percentage	Cumulative Difference	Cumulative Percentage
0	\$ 1,043,375	\$ 1,043,375	\$1,043,375	\$ 1,043,375	\$ -	0%	\$ -	0%
1	\$ 365,300	\$ 1,408,675	\$ 365,300	\$ 1,408,675	\$ -	0%	\$ -	0%
2	\$ 365,300	\$ 1,773,975	\$ 365,300	\$ 1,773,975	\$ -	0%	\$ -	0%
3	\$ 365,300	\$ 2,139,275	\$ 268,233	\$ 2,042,208	\$ (97,067)	27%	\$ (97,067)	5%
4	\$ 365,300	\$ 2,504,575	\$ 268,233	\$ 2,310,441	\$ (97,067)	27%	\$ (194,134)	8%
5	\$ 365,300	\$ 2,869,875	\$ 268,233	\$ 2,578,674	\$ (97,067)	27%	\$ (291,201)	10%
6	\$ 365,300	\$ 3,235,175	\$ 268,233	\$ 2,846,907	\$ (97,067)	27%	\$ (388,268)	12%
7	\$ 365,300	\$ 3,600,475	\$ 268,233	\$ 3,115,140	\$ (97,067)	27%	\$ (485,335)	13%

SYSTEM COSTS



Author: Peter Guest at PARDEN

Date: 12/22/98 10:18 AM

Priority: Normal

TO: , "Rowans, Patricia V, Ms, HQAFCEE" <Patricia.Rowans@HQAFCEE.brooks.af.mil> at NetTalk
Subject: Re[2]: Site 5/15 Costs

ATTACHMENT 25.01
✓ CC: P. Guest.

5 of 18

Pat: I received from AFCEE a seven page document (Project Number: FSPM 99-2053, Base request for 1999 funding, signed by Robert Wood, dated June 25, 1998) that provided an estimated cost for 1999 O&M. The estimated cost was \$276,000. Is it appropriate to use this cost estimate for 1999 O&M.

Also, within this document there is a reference to prior funding history. The numbers presented in this document include:

FY	Phase	Project No.	Cost (\$000)
95	IRA	95-7510 <i>Per Pat</i>	1,721.0 - <i>investigation</i>
96	IRA Expansion	96-7510	1,668.9 - <i>1,319,475 = TS Study</i>
98	O&M	98-2053	408.0
98	IRA Biovent	98-2072	163.0 } <i>requested for '99</i>

How do these numbers relate to the \$1,319,475 for the treatability study??
I can fax this document to you if you do not have it.

Thank you for your assistance. Pete

Reply Separator

Subject: RE: Site 5/15 Costs
Author: , "Rowans, Patricia V, Ms, HQAFCEE"
<Patricia.Rowans@HQAFCEE.brooks.af.mil> at NetTalk
Date: 12/21/98 2:52 PM

According to my file the cost of the TS Study at site 5/15 is \$1,319,475 (both installation and O & M). If you have any more questions, send me an e-mail or call me.

-----Original Message-----

From: Peter Guest [mailto:Peter_Guest@parsons.com]
Sent: Thursday, December 17, 1998 3:46 PM
To: patricia.rowans@hqafcee.brooks.af.mil
Subject: RE: Site 5/15 Costs

Pat: FYI If you have any cost data for the construction of the Site 5/15 treatment system, I would greatly appreciate it.

Pete

Forward Header

Subject: RE: Site 5/15 Costs
Author: , "Siegal,Joan" <JSiegal@earthtech.com> at NetTalk
Date: 12/15/98 12:24 PM

I need to review the O&M and plant constuction costs (your follow-on email) with Rebecca. I can give you answers to some of the below questions.

> -----Original Message-----

From: Peter Guest [SMTP:Peter_Guest@parsons.com]

Sent: Monday, December 14, 1998 1:59 PM

To: jsiegal

> Cc: John Ratz

> Subject: Site 5/15 Costs

>

> Joan: For the Site 5/15 Remediation Process Optimization project, it

>

> would be helpful to receive from you cost information for operating
> the Site 5/15 treatment system. I received a seven page document
> (Project Number: FSPM 99-2053, Base request for 1999 funding, signed
> by Robert Wood, dated June 25, 1998) from AFCEE that provided an
> estimated cost for 1999 O&M. The estimated cost was \$276,000. Is it

>

> appropriate to use this cost estimate or do you have actual numbers.

>

> I did not see cost information for the following:

>

> Annual Operation and Maintenance Cost

>

> Electricity [Siegal,Joan] We are not on a meter, and are not as
> of yet charged for electricity.

> Filter Bags [Siegal,Joan] \$47.50/bag. Assume 26 changes per
> year. Filter changes take a few minutes and are part of the routine O&M
> performed at the plant.

> Catalyst Replacement (if applicable) [Siegal,Joan] We have not
> done this yet. Estimated cost would be \$10,000 in material plus 2 persons
> x 8hrs labor.

> Analytical

> - Groundwater monitoring (was this included in cost

>

> estimate?)

[Siegal,Joan] Groundwater monitoring has been not included in the
O&M budgets, but has been part of other delivery orders, and has not been
tracked as a separate task. Future monitoring will be part of the Basewide
LTM Plan. With the recent installation of dedicated pumps (8 wells can now
be sampled per day), costs for LTM should drop, especially if lumped with
other sites. We have not yet calculated what the new costs would be.

> Labor for groundwater monitoring (was this included in cost

>

> estimate?) [Siegal,Joan] See above.

> Discharge fees (if applicable) [Siegal,Joan] We are not billed
> for these items.

> -Water

> -Free product

>

> Will the 1999 system monitoring schedule be the same as the schedules

>

> presented in Table 4.1 and 4.2 of the O&M Plan. [Siegal,Joan] We
> are presently in the process of revising Tables 4.1 and 4.2. All
> monitoring wells are now sampled semiannually. The carbon vessels are now
> off-line; recent samples of LPAS effluent have no detectable contaminants.
> General water quality and SVOCs have been dropped after the first year of
> operation.

>

> Thank you for your assistance. Pete

6 of 18

TABLE 5-2. COST SUMMARY FOR TREATMENT ALTERNATIVES

CAPITAL COSTS		OPTION 1	OPTION 2
EARTH TECH Labor			
	Work Plan/Design/Drawings/Specs	\$131,200	\$131,200
	Construction	\$82,900	\$82,900
	Subtotal Labor	\$214,100	\$214,100
Subcontractors			
	Drilling	\$120,300	\$120,300
	System Construction	\$312,300	\$312,100
	Treatment Equipment/Materials	\$500,700	\$623,400
	Analytical Laboratory	\$31,400	\$31,400
	Subtotal Subcontractors	\$964,700	\$1,087,200
ODCs			
	Field Expendables	\$10,800	\$10,800
	Field Equipment	\$30,200	\$30,200
	Travel/Transportation	\$27,300	\$27,300
	Miscellaneous ODCs	\$7,000	\$7,000
	Subtotal ODCs	\$75,300	\$75,300
	Total Capital costs	\$1,254,100	\$1,376,600
O&M COSTS			
EARTH TECH Labor (One Year)			
	O&M	\$43,200	\$43,200
	Progress Report (Treatability Investigation Report)	\$63,500	\$63,500
	Subtotal Labor	\$106,700	\$106,700
Subcontractors (One Year)			
	Utilities (Electricity and Fuel)	\$89,200	\$229,600
	Granular Activated Carbon	\$4,400	\$4,400
	Equipment service	\$4,800	\$4,800
	Hydrogen Peroxide and UV Lamps		\$205,800
	Other Materials	\$9,400	\$5,400
	Analytical Laboratory	\$91,300	\$91,300
	Subtotal Subcontractors	\$199,100	\$541,300
ODCs (One Year)			
	Field Expendables	\$7,700	\$7,700
	Field Equipment	\$22,000	\$22,000
	Travel/Transportation	\$11,100	\$11,100
	Miscellaneous ODCs	\$5,700	\$5,700
	Subtotal ODCs	\$46,500	\$46,500
	Total O & M Cost for one Year	\$352,300	\$694,500
	Total Net Present Cost for Additional 6 Years of O & M @ 7% Interest	\$1,679,200	\$3,310,300
	GRAND SUBTOTAL	\$2,933,300	\$4,686,900
	PROJECT ADMINISTRATION @ 7% OF GRAND SUBTOTAL	\$205,300	\$328,100
	CONTRACTOR OVERHEAD @ 10% OF GRAND SUBTOTAL	\$293,300	\$468,700
	CONTRACTOR PROFIT @ 10% OF GRAND SUBTOTAL	\$293,300	\$468,700
	CONTINGENCY @ 10% OF GRAND SUBTOTAL	\$293,300	\$468,700
	GRAND TOTAL	\$4,018,500	\$6,421,100

Note:

Costs have been rounded to the nearest one-hundred dollars

OPTION 1 - Dual Extraction System with Pneumatic Pump, Vacuum Blower, Oil Water Separator, Air Stripper, Liquid-phase Carbon, and Thermal/Catalytic Oxidizer with Scrubber

OPTION 2 - Dual Extraction System with Pneumatic Pump, Vacuum Blower, Oil Water Separator, UV Oxidizer Liquid-phase Carbon, and Thermal/Catalytic Oxidizer with Scrubber

See Appendix D-2 for Detailed Cost Breakdown

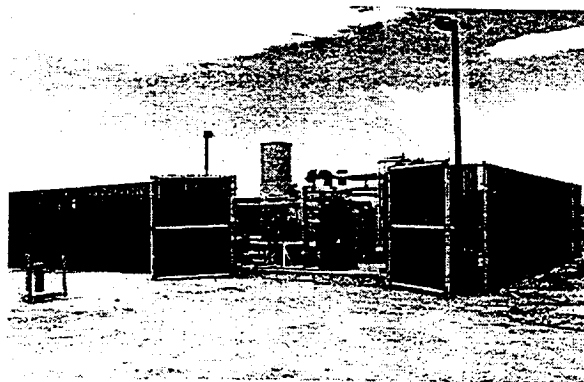
PROJECT NUMBER: FSPM 99-2053
PROJECT TITLE: IRA-O OU 2 Sites 5/15
LTO Dual Extraction Treatment System

PROJECT PRIORITY: 5A

DATE: 25 June 1998 INITIAL ()
REVISION (X)

1. **INSTALLATION:** Edwards AFB, CA (AFMC).

2. **REQUIREMENT:** This project provides Interim Removal Action (IRA) Long-Term Operations and Maintenance (O&M) services for the Installation Restoration Program (IRP) Sites 5/15 (ST-005 and SD-015) Dual Extraction Treatment System. The IRP Sites 5/15 are located in South Base Operable Unit 2 (Attachment 1). The treatment system is designed for a maximum groundwater extraction flow rate of 30 gallons per minute (gpm) and a maximum vapor flow rate of 550 standard cubic feet per minute (scfm).



Site 5/15 Soil Vapor Extraction Unit

3. **ESTIMATED COST:** \$276,000. The cost estimate was based on historical engineering pricing schedules from contractors and suppliers providing similar work and products in southern California. Estimated costs for FY99 (Attachment 2) are summarized as follows:

OU2 Site 5 O&M	FY99 Cost (\$000)
Labor	144.8
Other Direct Costs	9.5
Travel/Transportation	52.6
Subcontractors	8.6
Technical Support	7.2
Laboratory Analyses	53.4
TOTAL	276.1

4. **PURPOSE:** This project will provide O&M services, and the required water and air sampling/analyses for the Sites 5/15 Dual Extraction Treatment System.

5. **WORK TO BE PERFORMED:** Task 1 involves routine contractor support services that will include: visual inspection of all treatment system equipment and components, response to system shutdown alarms, performance of corrective maintenance on equipment as required, evaluation of system performance and assessment

of compliance with discharge requirements. Treatment system monitoring will include measuring/recording the following: blower vacuum, temperature, and airflow; catalyst temperature; fuel usage; recovered free product; water flow rates and quantity; incline filter pressure and temperature; carbon vessel inlet pressures and temperatures; and well pressure, vacuum, and water level. Task 2 involves conducting treatment system sample collection and analyses to include: air stripper inlet and outlet, lead and lag carbon canister outlet, catalytic oxidizer inlet and outlet, and carbon profile for disposal characterization. Task 3 involves providing quarterly O&M reports on the effectiveness of the treatment system.

6. **WORK SCHEDULE:** See Attachment 3.

7. **DATE FUNDING REQUIRED:** 15 February 1999.

8. **FUTURE WORK TO BE PERFORMED:** Treatment system O&M requirements are estimated to continue for a minimum of 5 years (FY00-FY04) at this IRA site, in order to reduce the contaminant source and to significantly reduce risk to human health and the environment.

9. **BACKGROUND:** The Sites 5/15 contaminant plume originated from former fuel storage depots that were constructed in the early 1940's when the original Main Base at Muroc Army Airfield was located at the area now known as South Base. The former fuel depots consisted of 26 various underground storage tanks (USTs) with capacities ranging from 3,000 to 50,000 gallons. During their general usage from the 1940's until the early 1980's, the USTs stored petroleum fuels and lubricants including waste jet fuels, gasoline, and motor oils. By 1994, all the former fuel depot USTs were removed. Soil samples collected during tank removal operations indicated that most of the USTs leaked.

Characterization and monitoring of petroleum hydrocarbon contamination at Sites 5/15 began in 1982. Detected soil and groundwater contaminants include floating free product, jet fuel, gasoline, oil and grease, halogenated solvents, aromatic hydrocarbons, semivolatile organic compounds (SVOCs), and ethylene dibromide. Maximum dissolved phase groundwater concentrations of benzene and trichloroethene (TCE) have been detected at 3,200 and 2,500 micrograms per liter ($\mu\text{g/L}$), respectively. Groundwater remedial investigations indicate that the contaminant plume extends 4,800 feet through the southwest corner of Site 15, beneath the former Muroc Army Airfield tarmac, and to Site 14 (the Fire Fighting Training Facility).

The treatment system consists of 10 dual extraction (groundwater and soil vapor) wells, 3 soil vapor extraction (SVE) wells, 1 dual-completion air sparge/SVE well, 2 air sparge wells, 10 pneumatic groundwater extraction pumps, an oil/water separator, an incline filter, an air stripper, an SVE blower, a water/vapor separator, a catalytic oxidizer, a dual-canister liquid phase granular activated carbon (GAC) vessel, an air compressor, and associated tanks, piping and valves. Sites 5/15 Treatment System construction began in February 1997 and startup occurred in April 1997.

FY	PHASE	PROJECT NO.	COST (\$000)
95	IRA	95-7510	1,721.0
96	IRA Expansion	96-7510	1,668.9
98	O&M	98-2053	408.0
98	IRA Biovent	98-2072	163.0

10. PROJECT RELATIVE RISK: Not Required (NR).

11. REGULATORY AGREEMENT/DEADLINES: Following Edwards AFB's formal listing on the National Priority List (NPL), on 30 August 1990, a Federal Facility Agreement (FFA) was signed by the U.S. Air Force, the U.S. Environmental Protection Agency (EPA) Region IX, California EPA Department of Toxic Substances Control (DTSC), and the California Regional Water Quality Control Board (RWQCB), Lahontan Region. Edwards AFB and the regulatory agencies have agreed to modify the original FFA schedule to incorporate the new accelerated CERCLA process. Unless progress can be shown by completing EE/CAs, Treatability Study Work Plans, and implementing IRAs, the Remedial Project Managers will hold Edwards AFB to the original FFA schedule and all of its deliverable documents.

12. IMPACT IF FUNDING IS NOT PROVIDED: If funding is not provided, the following project impacts will occur:

- Soil and groundwater contaminant concentrations at the Sites 5/15 area will exceed regulatory cleanup guidelines, and will not be reduced.
- Sites 5/15 treatment system will not be operated for FY99, resulting in \$3.7 million expenditures wasted.
- Sites 5/15 groundwater contaminants will continue to migrate.

13. SITE SUMMARY:

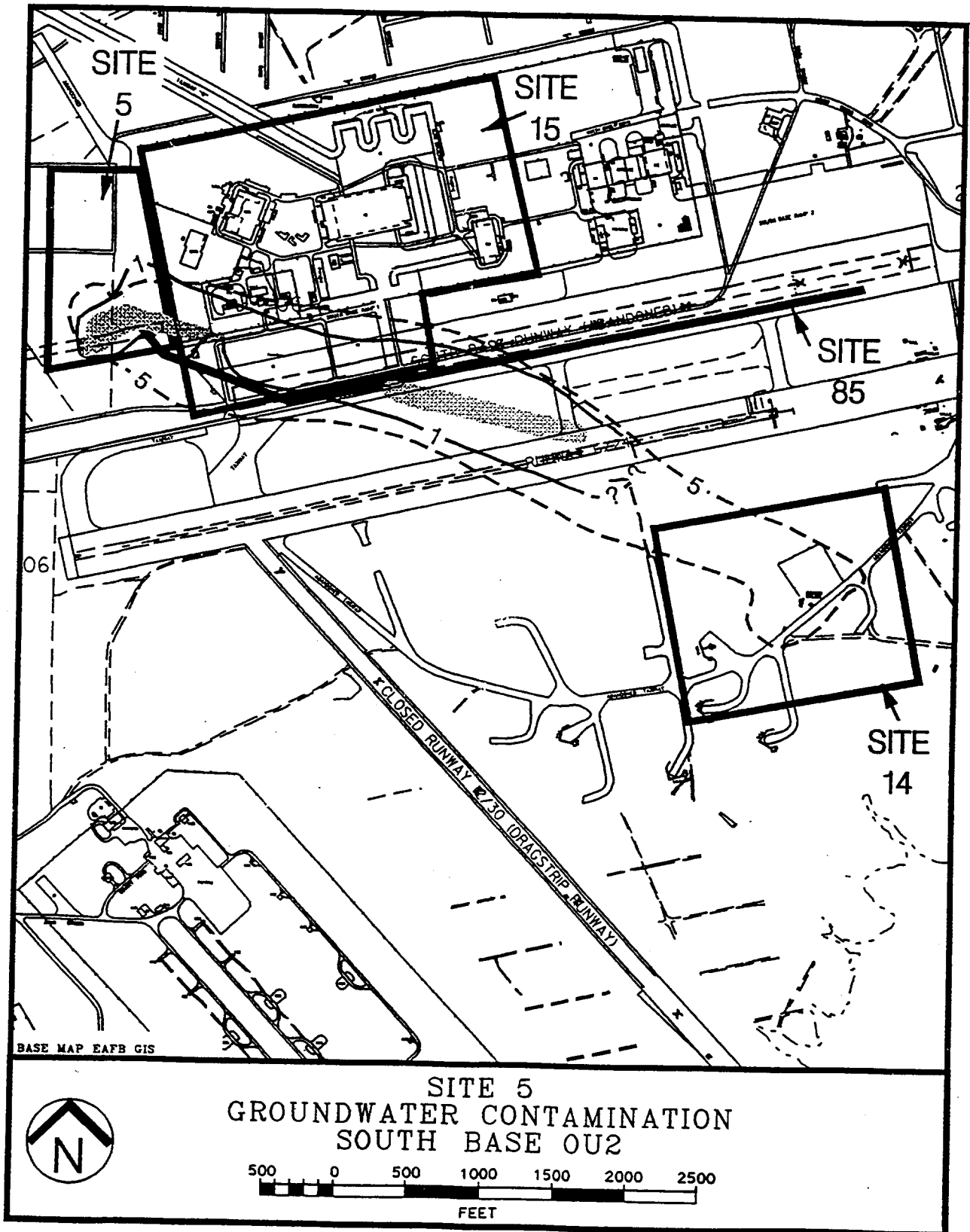
AFRIMS Phase: IRA-O
 Site Code: ST-005
 Site Description: South Base Former Fuel Depot
 Project Priority: 5A
 Relative Risk: NR
 Legal Driver Code: A
 Milestone Code: 12
 Milestone Date: 10/1/98
 EPIC Code: 53503
 Site Cost: \$276,000

14. **CONTRACTING AGENT:** Army Corps of Engineers.

15. I have reviewed this requirement and certify that it meets the eligibility criteria for use of ERA funds.

A handwritten signature in cursive script, appearing to read "Robert W. Wood", is written over a horizontal line.

ROBERT W. WOOD, Chief
Environmental Restoration Division



		Task1		Task 2		Task 3		TOTALS
		Field Work		Lab Analysis		Reports		
		units	cost	units	cost	units	cost	Cost
Direct Labor	FY99		\$83,845				\$60,961	144,806
Principal	97.42		\$0			\$0	\$0	
Program Manager	94.14	42	\$3,954			\$0	\$2,448	6,402
Project Manager	78.73	133	\$10,471			\$0	\$11,495	21,966
Safety/Health Officer	53.80	72	\$3,874			\$0	\$0	3,874
Civil Engineer	54.15	214	\$11,588			\$0	\$5,307	16,895
Geologist	48.37	298	\$14,414			\$0	\$967	15,381
Hydrologist	54.15	336	\$18,194			\$0	\$14,296	32,490
Chemist	48.37	68	\$3,289			\$0	\$1,548	4,837
GIS Sys Mgr	75.76		\$0			\$0	\$3,409	3,409
GIS Prog Mgr	58.71		\$0			\$0	\$3,405	3,405
GIS Technician	42.95		\$0			\$0	\$7,130	7,130
Field Technician	29.13	620	\$18,061			\$0	\$2,097	20,158
Tech Writer	43.25		\$0			\$0	\$1,038	1,038
WP/Clerical	26.35		\$0			\$0	\$843	843
CADD Operator	42.95		\$0			\$0	\$2,749	2,749
Data Processor	24.88		\$0			\$0	\$4,230	4,230
Other Direct Costs	Rate							9,511
Personal Computer/CAD Usage	5.00 /hour	55	\$275			\$0	\$885	1,160
GIS Usage	17.00 /hour		\$0			\$0	\$935	935
Reproduction	0.05 /copy	84	\$4			\$0	\$78	88
Oversize Mylars	35.72 /copy		\$0			\$0	\$0	
Folded Oversize Bluelines	1.19 /copy	8	\$10			\$0	\$0	10
Film & Development	18.27	2	\$37			\$0	\$18	55
Telephone/FAX	5.00 /call	44	\$220			\$0	\$340	560
Express Shipping (2-day)	6.00 /pkg		\$0			\$0	\$96	96
Graphics Support	31.00 /hour		\$0			\$0	\$868	868
Film & Development	14.07 /roll		\$0			\$0	\$0	
Field Expendables	500 Unit	6	\$3,000			\$0	\$0	3,000
Field Equipment	250 Unit	8	\$2,000			\$0	\$0	2,000
Well Permit			\$0			\$0	\$0	
ODC @ 8.6%			\$477			\$0	\$277	754
Travel/Transportation	Rate /day							52,561
Car Rental	49.90 /day		\$0			\$0	\$200	200
Field Vehicle Rental (4x4)	82.38 /day		\$0			\$0	\$0	
Field Vehicle Rental (4x4)	500.94 /wk		\$0			\$0	\$0	
Field Vehicle Rental (4x4)	1,487.11 /mo	12	\$17,845			\$0	\$0	17,845
Full Per Diem (EAFB/LGB)	120.00 /day	247	\$29,640			\$0	\$720	30,360
Parking	7.00		\$0			\$0	\$0	
Local Mileage	0.31		\$0			\$0	\$0	
Travel @ 8.6%			\$4,084			\$0	\$79	4,163
Subcontractors	Rate							62,044
Carbon Services			\$7,924			\$0	\$0	7,924
Treatment Services	160		\$0			\$0	\$0	
Smeal Rig(Purging and Sampling)	500		\$0			\$0	\$0	
Laboratory Services			\$0			\$0	\$0	
Water						\$22,551	\$0	53,439
Air						\$30,888		
Markup @ 8.6%			\$681			\$0	\$0	1,362
Technical Support @ 5%(DL)			\$4,192			\$0	\$3,048	7,240
Project Totals	(DL+ODC+T/T+S/C)		\$88,312		\$53,439		\$64,894	276,177

FSPM 99-2053
OU2 Site 5/15 IRA LTO Dual Extraction System

ID	Task Name	Start	Finish	1999											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	OU2 Site 5/15 IRA LTO Dual Extraction System	1/15/99	3/31/00												
2	SOW	1/15/99	2/15/99												
3	Funds Received	2/15/99	3/1/99												
4	ACOE Award Contract	3/1/99	4/1/99												
5	Site 5/15 Operations & Maintenance	4/1/99	3/31/00												
6	System Operation	4/1/99	3/31/00												
7	System Monitoring - Sampling & Analysis	4/1/99	3/31/00												
8	Quarterly Report	3/23/99	3/1/00												
19	Report 1	4/1/99	6/1/99												
20	Report 2	6/30/99	9/1/99												
21	Report 3	9/30/99	12/1/99												
22	Report 4	12/31/99	3/1/00												

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South Base Former Fuel Depot	Task	Milestone	Roll Up Task	Roll Up Progress
	Progress	Summary	Roll Up Milestone	

TABLE 2.2-8. MASS OF CONTAMINANTS REMOVED IN VAPOR, DISSOLVED, AND FREE PHASES

Contaminant	Vapor Phase		Mass Removed (Pounds)		Free Phase (Free Product)	
	Reporting Period ^(a)	Cumulative ^(b)	Reporting Period ^(a)	Cumulative ^(b)	Reporting Period ^(a)	Cumulative ^(b)
Total of all Organics	16,478	350,597	43	417	216	4,147
Benzene	30	1,083	0.1	6.4	NA	NA
TCE	27	892	0.7	7.4	NA	NA

Notes:

(a) Mass removed from 7/31/98 to 1/31/99.

(b) Cumulative mass removed from 4/21/97 (start-up) to 1/31/99.

NA = Not available (See Section 2.2.6.3)

contaminants removed in the vapor phase during the reporting period and the cumulative mass removed since start-up of the DES on April 21, 1997. The average mass removal rates for the total organic contaminants (i.e., TVPH), benzene, and TCE in the vapor phase, during the reporting period, are summarized in Table 2.2-9.

TABLE 2.2-9. AVERAGE CONTAMINANT MASS REMOVAL RATES IN VAPOR, DISSOLVED, AND FREE PHASES

Contaminant	Vapor Phase (lbs/day)	Dissolved Phase (lbs/day)	Free Product (lbs/day)
Total of All Organics	186	0.51	49
Benzene	0.34	0.001	NA
TCE	0.31	0.008	NA

Notes:

Mass removal rate based on the mass removed for the quarterly period divided by the number of hours on-line

(see Table 2.1-1) multiplied by 24 hrs/day.

NA = Not available (See Section 2.2.6.3)

2.2.6.2 Dissolved Phase

The mass of the contaminants removed in the dissolved phase is based on the analytical results of groundwater samples collected at the discharge from the equalization tank (Sample Port SW27) and the volume of groundwater extracted [measured at Flowmeter FE-4000 (see Figure 1.2-2)]. To calculate the total mass of contaminants removed, the higher concentration of either TVPH (determined by Method 8015V) or TEPH (determined by Method 8015D) was used.

mass removal calculations are presented in Appendix D-1, along with a discussion of the procedures and assumptions used in the calculations.

The cumulative total mass of contaminants removed in the vapor phase versus time, through January 22, 1999, is illustrated on Figure 2.2-3. The cumulative mass of benzene and TCE removed as a function of time is illustrated on Figure 2.2-4 and Figure 2.2-5, respectively. Table 2.2-8 presents the calculated mass of contaminants removed in the vapor phase during the reporting period and the cumulative mass removed since start-up of the DES on April 21, 1997. The average mass removal rates for benzene and TCE in the vapor phase during the reporting period are summarized in Table 2.2-9.

TABLE 2.2-8. MASS OF CONTAMINANTS REMOVED IN VAPOR, DISSOLVED, AND FREE PHASES

Contaminant	Vapor Phase		Mass Removed (Pounds)		Free Phase (Free Product)	
	Reporting Period ^(a)	Cumulative ^(b)	Reporting Period ^(a)	Cumulative ^(b)	Reporting Period ^(a)	Cumulative ^(b)
Total of all Organics	Not calculated	*	63	473.2	552	4,698
Benzene	22	1,104	0.5	6.9	NA	NA
TCE	18	909	0.8	8.1	NA	NA

Notes:

(a) Mass removed from 1/28/99 to 4/22/99.

(b) Cumulative mass removed from 4/21/97 (start-up) to 4/22/99.

NA = Not available (See Section 2.2.6.3)

*** SEE LAST REPORTING PERIOD**

TABLE 2.2-9. AVERAGE CONTAMINANT MASS REMOVAL RATES IN VAPOR, DISSOLVED, AND FREE PHASES

Contaminant	Vapor Phase (pounds/day)	Dissolved Phase (pounds/day)	Free Product (pounds/day)
Total of All Organics	Not calculated	2.1	7.1
Benzene	0.27	0.006	NA
TCE	0.23	0.01	NA

Notes:

Mass removal rate based on the mass removed for the quarterly period divided by the number of hours on-line (see Table 2.1-1) multiplied by 24 hrs/day.

NA = Not available (See Section 2.2.6.3)

Direct Labor	FY99	% RED	Task 1 Field Work		Task 2 Lab Analysis		Task 3 Reports		TOTALS
			units	cost	units	cost	units	cost	
Principal	97.42			\$88,845 → 70675		\$0		\$60,961	14,000
Program Manager	94.14	0%		\$0		\$0		\$0	
Project Manager	78.73	0%	42	\$3,954		\$0	26	\$2,448	6,4
Safety/Health Officer	53.80	0%	133	\$10,471		\$0	146	\$11,495	21,9
Civil Engineer	54.15	15%	72	\$3,874		\$0		\$0	3,8
Geologist	48.37	15%	182	\$11,588 → 9855		\$0	98	\$5,307	16,8
Hydrologist	54.15	15%	254	\$14,114 → 12386		\$0	20	\$967	15,3
Chemist	48.37	15%	286	\$16,194 → 15487		\$0	264	\$14,296	32,4
GIS Sys Mgr	75.76		58	\$8,209 → 2805		\$0	32	\$1,548	4,8
GIS Prog Mgr	58.71			\$0		\$0	45	\$3,409	3,4
GIS Technician	42.95			\$0		\$0	58	\$3,405	3,4
Field Technician	29.13	33%	410	\$10,001 → 11943		\$0	166	\$7,130	7,1
Tech Writer	43.25			\$0		\$0	72	\$2,097	20,1
WP/Clerical	26.35			\$0		\$0	24	\$1,038	1,0
CADD Operator	42.95			\$0		\$0	32	\$843	84
Data Processor	24.88			\$0		\$0	64	\$2,749	2,74
Other Direct Costs		Rate		\$0		\$0	170	\$4,230	4,23
Personal Computer/CAD Usage	5.00 /hour		55	\$275		\$0	177	\$885	9,51
GIS Usage	17.00 /hour			\$0		\$0	55	\$935	93
Reproduction	0.05 /copy		84	\$4		\$0	1550	\$78	8
Oversize Mylars	35.72 /copy			\$0		\$0		\$0	
Folded Oversize Bluelines	1.19 /copy		8	\$10		\$0		\$0	1
Film & Development	18.27		2	\$37		\$0	1	\$18	5
Telephone/FAX	5.00 /call		44	\$220		\$0	68	\$340	
Express Shipping (2-day)	6.00 /pkg			\$0		\$0	16	\$96	9
Graphics Support	31.00 /hour			\$0		\$0	28	\$868	86
Film & Development	14.07 /roll			\$0		\$0		\$0	
Field Expendables	500 Unit		6	\$3,000		\$0		\$0	3,00
Field Equipment	250 Unit		8	\$2,000		\$0		\$0	2,00
Well Permit				\$0		\$0		\$0	
ODC @ 8.6%				\$477		\$0		\$277	75
Travel/Transportation	Rate /day					\$0			52,56
Car Rental	49.90 /day			\$0		\$0	4	\$200	20
Field Vehicle Rental (4x4)	82.38 /day			\$0		\$0		\$0	
Field Vehicle Rental (4x4)	500.94 /wk			\$0		\$0		\$0	
Field Vehicle Rental (4x4)	1,487.11 /mo		12	\$17,845		\$0		\$0	17,84
Full Per Diem (EAFB/LGB)	120.00 /day	33%	247	\$29,640 → 1980		\$0	6	\$720	30,36
Parking	7.00		163	\$0		\$0		\$0	
Local Mileage	0.31			\$0		\$0		\$0	
Travel @ 8.6%				\$4,084 → 3217		\$0		\$79	4,163
Subcontractors	Rate								
Carbon Services				\$7,924 → 0		\$0		\$0	7,924
Treatment Services	160			\$0		\$0		\$0	0
Smeal Rig(Purging and Sampling)	500			\$0		\$0		\$0	0
Laboratory Services				\$0		\$0		\$0	0
Water				\$0		\$0		\$0	53,439
Air				\$22,351 → 0		\$0		\$0	
Markup @ 8.6%				\$30,888					
Technical Support @ 5%(DL)				\$4,102 → 3534		\$0		\$3,048	1
Project Totals (DL+ODC+T/T+S/C)				\$88,845 → 120,854		\$50,409 → 30888		\$64,894	276,177

TOTAL = 216,600

✓ ASSUME INLET FLOW-RATE AFTER TERMINATION OF LPAS (~500 scfm) AND 20% REDUCTION IN SOIL VAPORS TREATED 520 scfm OF [1,150 scfm - 500 scfm - 130 scfm] = 520 scfm COMPARED TO DESIGN OF 1,300 scfm OR 40% OF TOTAL - ADJUST FUEL/ELEC AS SUCH

Annual Operation and Maintenance Costs
SITE 5 - OPERABLE UNIT 2
ENGINEERING EVALUATION/COST ANALYSIS
EDWARDS AFB, CA

Assumption:
Operational Period = 1 Year

DUAL EXTRACTION SYSTEM

ITEM	Item Includes	Unit Rate (\$)	Unit of Measure	Quantity	Total Cost (\$)	Source
UTILITIES						
Pneumatic Pump	Continuous operation of 20 hp compressor	0.1	KW hr	130,647	13,065 13,065	EARTH TECH
Vacuum Extraction Blower	Continuous operation of 60 hp motor	0.1	KW hr	391,940	39,194	EARTH TECH
Low Profile Air Stripper	Continuous operation of 5 hp blower	0.1	KW hr	32,662	3,266 3,266	EARTH TECH
	Continuous operation of 2 hp feed pump	0.1	KW hr	13,065	1,307 1,307	EARTH TECH
	Continuous operation of 2 hp discharge pump	0.1	KW hr	13,065	1,307 1,307	EARTH TECH
	Fuel and electricity	3.6	hour	8,760	31,008 31,008	Global Tech
Thermal/Catalytic Oxidizer					89,236 89,236	12439
SUB-TOTAL UTILITIES COST						
MAINTENANCE						
Liquid Phase Carbon - Transport and Regeneration	Transportation to an EPA approved facility	1,970	each	2	3,940	Wheelabrator
Spent Carbon Profiling Fee	Fee paid once every two years	450	each	1	450	Wheelabrator
SUB-TOTAL GAC COST						
Equipment Service	Subcontractor Work	400	month	12	4,800	EARTH TECH
SUB-TOTAL EQ. SERVICE COST						
Pneumatic Pump	Materials	40	month	12	480	EARTH TECH
Vacuum Extraction Blower	Materials	-	Lump Sum	-	239	Pego Systems
Oil/Water Separator	Materials	50	month	12	600	EARTH TECH
Blowers and Pumps	Materials	150	month	12	1,800	EARTH TECH
Air Stripper	Materials	100	month	12	1,200	EARTH TECH
Thermal/Catalytic Oxidizer	Materials	-	Lump Sum	-	3,000	Global Tech
Thermal/Catalytic Oxidizer	Sodium Hydroxide	0.16	per pound	13,140	2,102	Global Tech
SUB-TOTAL OTHER MATERIALS						
TOTAL MAINTENANCE COST						
TOTAL ANNUAL O & M COSTS						
					11,292	
					98,657	